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CARRIER BASED AIR LOGISTICS STUDY: SUPPLY AND TRANSPORTATION AN--ETC(U)

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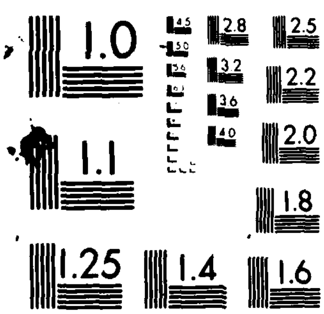

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The Carrier Based Air Logistics Study (CABAL) was conducted to examine alternative logistics support policies for avionics equipment with respect to their potential to improve aircraft availability and performance in wartime. The study considered avionics components on six aircraft types that are included in most carrier deckloads--the F-14A, S-3A, E-2C, and three A-6 variants. This Note documents the analysis, findings, and conclusions of the CABAL supply and transportation analysis. Although the CABAL analysis indicated that the DRMS shore repair alternative, in general, is not currently attractive, a number of opportunities for improvement in current policies and procedures are identified.

A RAND NOTE

CARRIER BASED AIR LOGISTICS STUDY:
SUPPLY AND TRANSPORTATION ANALYSIS

R. J. Hillestad, L. B. Embry

April 1982

N-1785-NAVY

Prepared For

The Department of the Navy

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Rand
SANTA MONICA, CA. 90406

PREFACE

The Carrier Based Air Logistics (CABAL) Study had two primary purposes: (1) to evaluate an alternative logistics support structure suggested for further analysis in the Defense Resource Management Study (DRMS) report to the Secretary of Defense (February 1979) and (2) to identify and evaluate potential improvements in the current logistics support structure that could enhance aircraft availability during wartime without the complete structural change required by the DRMS alternative.

The study considered avionics components on six aircraft types that are included in most carrier deckloads--the F-14A, S-3A, E-2C, and three A-6 variants. It focused on key logistics elements that support carrier aircraft, including the supply system, shipboard component repair facilities (including test equipment), maintenance manpower for the repair facilities, and transportation for resupply of components not reparable aboard ship and for components to be repaired at depot facilities. Two key elements of the DRMS recommendation--the proposals to consolidate squadrons of like-type aircraft and to establish a responsive transportation system--were considered in separate studies by the Center for Naval Analyses (CNA).

This Note describes in further detail the CABAL supply and transportation analysis summarized in Rand Report R-2853-NAVY, <u>Carrier Based Air Logistics Study: Integrated Summary</u>. Three companion reports describe other aspects of the analysis:

CABAL Data Sources and Issues [Ref. 3]

CABAL Dyna-METRIC [Ref. 4]

CABAL Maintenance Analysis [Ref. 9]

This work was sponsored by the Office of the Chief of Naval Operations (OP-51).

SUMMARY

The Carrier Based Air Logistics Study (CABAL) was conducted to examine alternative logistics support policies for avionics equipment with respect to their potential to improve aircraft availability and performance in wartime. Towards this end, its objectives were to: (1) evaluate an alternative logistics support structure identified for further analysis in the Defense Resource Management Study (DRMS) and (2) identify and evaluate potential improvements in the current logistics support structure that could enhance wartime aircraft availability without the complete structural change implied by the DRMS alternative. The study considered the entire logistics support system and the interaction of its various functions and resources through a detailed examination of expected avionics suite availability under alternative logistics structures and policies. The analysis focused on six aircraft types included in most carrier deckloads--the F-14A, S-3A, E-2C, and three A-6 variants. Most of the substantive results presented here are based on analysis of avionics suite support for the first three aircraft type/model/series (TMS) listed above.

BACKGROUND

The Defense Resource Management Study (DRMS) [Ref. 14] included a preliminary analysis of carrier-based air logistics support as part of its investigation of logistics support alternatives for a variety of combat weapon systems. The study suggested that low peacetime aircraft availability was a major problem and identified alternative policies which might improve both peacetime readiness and wartime operational performance.

The DRMS suggested that the relatively small size of carrier squadrons (combined with existing stockage, maintenance manpower, and test equipment requirements policies) was a primary cause of the aircraft availability problem. For each carrier the logistics system has to support seven to eight different aircraft types assigned to nine to ten squadrons, each having a small number of aircraft--as few as four and as many as 12.

Small aircraft populations mean small scale in logistics operations. A number of areas were identified in which the relatively small scale, coupled with resource requirement policies, might have an adverse effect on logistics support. With a demand-based stockage policy, the quantity of on board spares is limited by the low demand generated by the small numbers of each type of aircraft, making it difficult to stock the extremely wide range of parts that could be required to repair aircraft components. The limited range of on board repair parts can result in long awaiting parts (AWP) time, thus slowing the component repair process.

Test equipment requirement policies are different from those for providing spare parts. Typically, test equipment is provided if there is demand for on board repair. Thus, the range of aircraft that must be supported is the basis of requirements for many different types of test equipment. Because most equipment is highly specialized and testing demands are low, test equipment utilization tends to be low. This, coupled with the demand-based stockage policy, makes it difficult to stock the range of test equipment repair parts that might be required. It is also difficult to provide the necessary maintenance skills and

calibration equipment because of the diverse range of equipment to be supported.

There is a similar problem in the requirements for manpower. The manpower requirement for intermediate-level repair personnel assigned to each squadron is based on the squadron's workload spread across numerous naval enlisted classifications (NECs). If there is a repair requirement, no matter how small the projected workload, a billet is required. Again, because of the small size of each squadron, many of these personnel have small workloads and low utilization.

Based on a limited analysis of these issues, the DRMS recommended further investigation and evaluation of a logistics support alternative that would move some intermediate-level repair from the carrier to shore-based Aircraft Intermediate Maintenance Departments (AIMDs). This move would increase the scale of repair by consolidating the requirements for manpower, test equipment, and repair parts at fewer locations. The hypothesis was that (1) reduced manpower requirements would provide savings that could be used for additional spare components on board the carrier or for improved transportation; (2) AWP time would be reduced; and (3) test equipment utilization and availability would be improved. The results also suggested that reduced AWP time and improved test equipment availability would reduce repair times.

In addition to suggesting that some of the component repair could be moved to shore-based facilities, the DRMS recommended that a more responsive transportation system be investigated since it would benefit both the shore repair alternative and current support structure. It recommended that utilization of manpower could be improved by cross

training (creating billets with dual NECs) and by using the scale represented by the total AIMD workload to determine manning requirements (rather than segmenting workload by squadron and aircraft type).

RESULTS

A key task of the CABAL study was to fully evaluate the DRMS findings with more complete and more recent data. In addition to examining the DRMS recommendations, including the shore repair alternative, the CABAL study was to identify and evaluate other options which might improve the performance of the current logistics support structure.

This Note documents the analysis, findings, and conclusions of the CABAL supply and transportation analysis. Although the CABAL analysis indicated that the DRMS shore repair alternative, in general, is not currently attractive, a number of opportunities for improvement in current policies and procedures were identified.

<u>The analysis showed that current supply policies do not provide the mix, or in some cases the level, of assets needed to maintain high aircraft material readiness rates in wartime</u>. These supply policy deficiencies are exacerbated by the poor peacetime performance of the transportation system, which can be expected to degrade during the early stages of a war. <u>The analysis also showed that using an aircraft availability objective rather than a requisition "fill rate" criterion for establishing stock levels would significantly improve performance without cost increases</u>. A methodology for employing an availability objective in requirements computation, and an estimate of the constant-cost performance improvements it should produce, are described in this Note.

ACKNOWLEDGMENTS

The CABAL study could not have been performed without excellent cooperation from the Navy. Admiral P. H. Speer (OP-05B) and the entire Navy Advisory Board provided useful advice and criticism which contributed to the balance and credibility of the analysis. The study benefited immensely from the many helpful comments and criticisms of Admiral R. W. Carius (OP-51) and his staff. Captain Charles Bolinger and his assistant, Lt. Commander Stanley Hunter, were instrumental in steering us to the right agencies and persons for data acquisition, orientation, and expert opinion. Without exception, Navy personnel at all levels were frank, open, and cooperative in their interactions with the CABAL study group.

We wish to thank Frank Swofford of the Navy Secretariat for his encouragement and support throughout the study. Our special thanks to our secretary, Dee Saenz, for keeping the administrative details of trips, meetings, and paperwork from completely engulfing us. Thanks also to Dee and Suzi Jackson for their support in the final documentation.

CONTENTS

FIGURES

TABLES

GLOSSARY

3M	Maintenance and Material Management System
AECL	Avionic Equipment Configuration List
AIMD	Aircraft Intermediate Maintenance Department
ASO	Aviation Supply Office
ASW	Antisubmarine Warfare
AVCAL	Aviation Consolidated Allowance List
AWP	Awaiting Parts
BCM	Beyond the Capability of Maintenance
CABAL	Carrier Based Air Logistics Study
CANN	Cannibalization
CATS	Computer Aided Test Set
CNA	Center for Naval Analyses
COMM	Communications
CV	Carrier
DRMS	Defense Resource Management Study
Dyna-METRIC	Dynamic Multi-Echelon Technique for Reparable Item Control
ELEC	Electrical
EXREP	Expedited Repair
FMC	Fully Mission Capable
FMCA	Fully Mission Capable for Avionics
HATS	Hybrid Automated Test Set
I-Level	Intermediate Level
IMA	Intermediate Maintenance Activities
INS	Inertial Navigation System

INST	Instruments
IO	Indian Ocean
LOR	Level of Repair
MOD	Module
NALCOMIS	Naval Aviation Logistics Command Management Information System
NARF	Naval Air Rework Facility
NAS	Naval Air Station
NATO	North Atlantic Treaty Organization
NAVMMACLANT	Navy Manpower and Material Analysis Center, Atlantic
NAV	Navigation
NEC	Naval Enlisted Classification
NMC	Non Mission Capable
NMCM	Non Mission Capable--Maintenance
NMCS	Non Mission Capable--Supply
O-Level	Organizational Level
O&ST	Order and Ship Time
PMC	Partially Mission Capable
POE	Projected Operational Environment
RIMSTOP	Retail Inventory Management Stockage Policy
ROC	Requirement for Operational Capability
SACE	Semi-Automatic Checkout Equipment
SAVAST	Ships AVCAL Assets Demand Tape
SCIR	Subsystem Capability Impact Report
SQMD	Squadron Manning Document
SRA	Shop Replaceable Assembly

TAD	Temporary Additional Duty
TYCOM	Type Commander
VAST	Versatile Avionics Shop Test
VSL	Variable Safety Level
WRA	Weapon Replaceable Assembly

I. INTRODUCTION

The Carrier Based Air Logistics (CABAL) study examined alternative logistics policies and structures for support of avionics equipments installed on six aircraft included in most aircraft carrier deckloads--the E-2C, F-14A, S-3A, and three A-6 variants. It considered the entire logistics support system for component repair and the interaction of its various elements, including maintenance, supply, and transportation. Although all echelons of the support system play a role in supporting aircraft avionics, the intermediate level of support has a direct effect on aircraft availability and wartime performance capability. Hence most of the analysis of policy options centered on what has traditionally been the shipboard level of support.

BACKGROUND

The Defense Resource Management Study (DRMS) [Ref. 14] included a preliminary analysis of carrier-based air logistics support as part of an investigation of logistics support alternatives for a variety of combat weapon systems. The results suggested that low peacetime aircraft availability was a major problem and presented preliminary analyses to identify alternative policies which could improve both peacetime readiness and wartime operational performance.

A key task of the CABAL study was to evaluate the DRMS findings using more complete and more recent data. In addition to examining the DRMS recommendations, including the shore repair alternative, the CABAL study was to identify and evaluate other options which might improve the performance of the current logistics support structure. If such options

did show promise, they might be preferable to the shore repair alternative. This investigation was to be based on a cross-functional analysis of the interdependent elements of the logistics support system. It was also to consider the implementation issues raised by its recommendations for improving wartime aircraft availability.

SUPPLY SUPPORT AND THE MAINTENANCE PROCESS

Navy aircraft maintenance involves both on-equipment and off-equipment work. On-equipment work identifies and replaces defective components at the aircraft. Off-equipment maintenance includes repair of the components replaced on the aircraft. These two types of maintenance capabilities and responsibilities are distributed across three levels of maintenance:

- Organizational (O-level)
- Intermediate (I-level)
- Depot

The organizational level performs most on-equipment maintenance. After troubleshooting and isolating a defective component, the O-level mechanic removes the component and replaces it with a spare drawn from local (retail) supply. These remove-and-replace maintenance actions create demands on the supply system. Supply stock levels and transportation capability, as well as off-equipment maintenance, exist to support on-equipment maintenance.

The primary source of supply for the components installed by the organizational level is intermediate-level maintenance. Most avionics Weapon Replaceable Assemblies (WRAs) are reparable; they are "black

boxes" that can be repaired at a fraction of their procurement cost by replacing Shop Replaceable Assemblies (SRAs--which are themselves reparable) and/or other components. Over 80 percent of the WRAs considered in the CABAL study are restored to service by the carrier or Naval Air Station (NAS) Aircraft Intermediate Maintenance Department (AIMD).

The 20 percent of WRAs, and 35 to 40 percent of SRAs, that are not repaired by the AIMD are evacuated to a Naval Air Rework Facility (NARF) or contractor's plant for depot-level maintenance. Components repaired at the depot level are returned to wholesale supply stocks. They are used to satisfy requisitions to replenish retail-level inventories (or meet organizational-level maintenance demands when repairs are Beyond the Capability of Maintenance (BCM) at the I-level).

Since the AIMD is the primary local source of supply for reparable components stocked at the retail level, I-level maintenance performance is a primary determinant of both local supply performance and aircraft operational availability. If maintenance turnaround times exceed those assumed in the development of supply stockage requirements, repair pipelines[1] will be unbalanced. The excess assets in the repair segment of the pipeline will be drawn from other available pools of stock--including, if necessary, the aircraft that the logistics system exists to support.

The logistics system described in the previous paragraphs is portrayed in Fig. I-1. It shows the three levels of Navy aircraft

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[1] The logistics system can be viewed as a series of pipelines through which supply assets flow between different pools of stock. This concept of pipelines is fundamental to the analysis described in this Note.

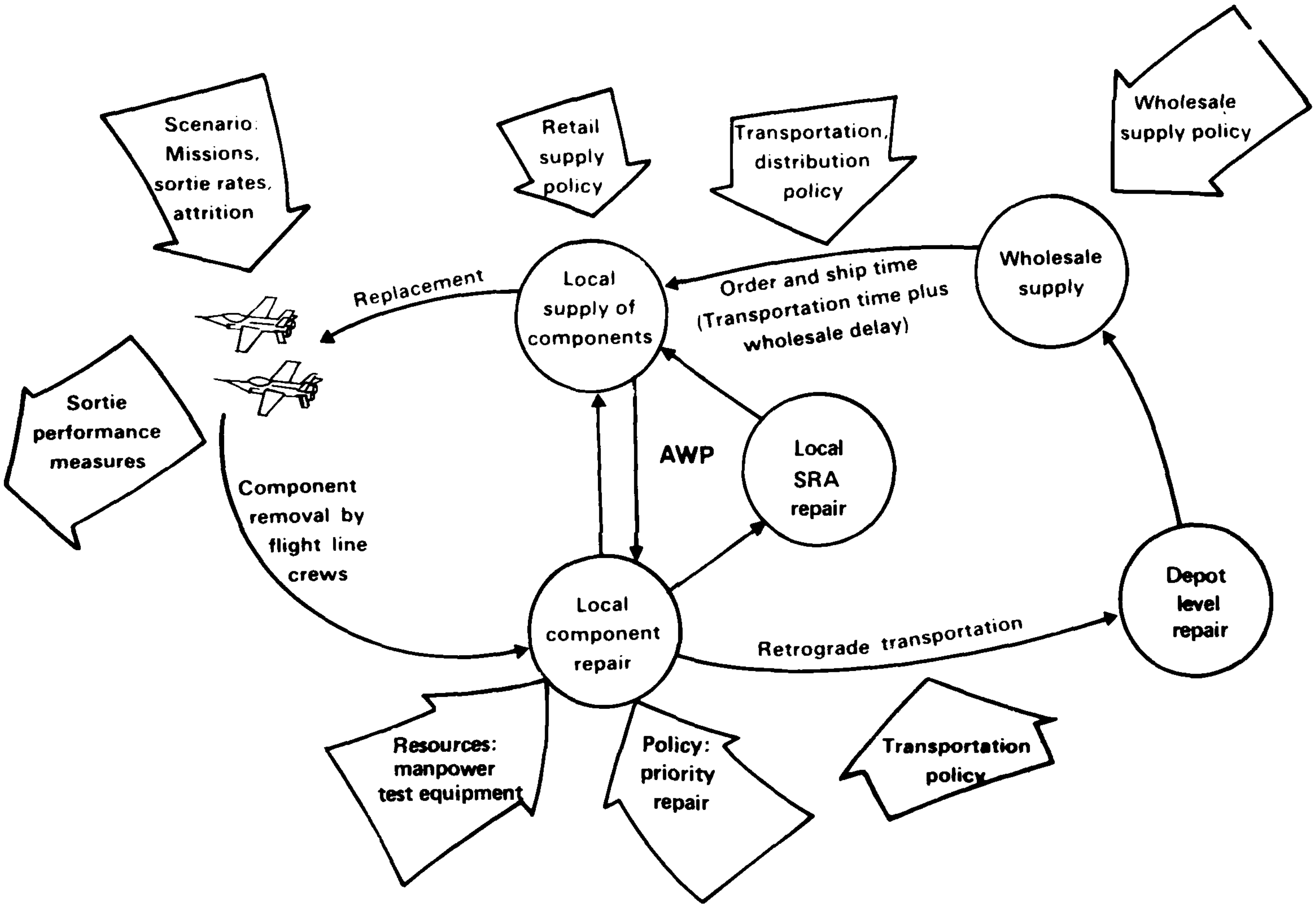

Fig. I-1—Pipeline model of the two-echelon inventory and maintenance system for aircraft component repair

maintenance, which create a requirement for two levels of supply--at the retail and wholesale levels. Retail stocks support both on- and off-equipment maintenance on board the carrier. Wholesale stocks replenish retail-level inventories and support depot-level maintenance.

Retail stock levels are authorized by the Aviation Consolidated Allowance List (AVCAL), a requirements document produced by the Navy Aviation Supply Office (ASO). Most AVCAL levels are based on component demand rates, the rate at which failed components can be regenerated by intermediate-level maintenance, and repair/resupply times. The rules used to select the components to be stocked and the depth[2] of stockage are described in Chap. III.

Wholesale requirements are established by the Navy's Uniform Inventory Control Point (UICP) system, which projects peacetime demand and levels requirements. Levels include a Variable Safety Level (VSL) which varies as a function of component unit price and demand rate. These peacetime levels are backed up by war reserve requirements to support increased wartime levels.

These stock levels cover logistics system pipelines.[3] They account for the assets that are expected to be tied up in repair or transportation, and provide a safety level of stock to account for the variability of demand, repair, and resupply times.

This Note describes in further detail the supply and transportation analysis summarized in Chap. IV of the CABAL Integrated Summary Report

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[2] The depth of stockage is the quantity of a particular component that is stocked. The range of stockage refers to the number of different components stocked.

[3] The logistics system can be visualized as a series of pipelines through which assets flow between stockage points. The pipeline quantity is thus the expected number of assets tied up in the pipeline, or demands per day times the service time (in days).

[Ref. 8]. Chapter II provides an overview of the methodology employed in this portion of the analysis. Chapter III then elaborates the methodological discussion by describing the current Navy AVCAL process and the AVCAL approximation developed to support the study.

With this methodological background, Chap. IV projects aircraft material condition assuming current supply and transportation policies. Chapter V describes a series of supply policy options that could improve the performance of the current logistics structure. Chapter VI discusses the effects of transportation on logistics system performance, and identifies potential improvements in transportation and related supply policies.

The findings and recommendations resulting from the detailed analysis reported in Chaps. IV-VI are given in summary sections at the end of each chapter. The Conclusions and Recommendations chapter of the CABAL Integrated Summary [Ref. 8] relates these supply and transportation results to the conclusions of the maintenance analysis.

II. METHODOLOGICAL APPROACH

The methodological approach to the CABAL study consisted of three prin y tasks:

- o Scenario definition.
- o Data base development.
- o Modeling and data analysis.

This chapter presents an overview of the methodological approach to aid in understanding the analysis and the basis for the recommendations in subsequent chapters.

SCENARIO DEVELOPMENT

Most Navy resource requirements methodologies reflect the assumptions of classical failure theory, which associates the failures of aircraft components with aircraft utilization expressed in flying hours. The CABAL study also assumed this linear relationship between failures (which generate maintenance workload and pipeline stockage requirements) and flying activity. It was therefore necessary to develop a scenario that would generate a flying program consistent with Navy wartime planning as a prerequisite to projection of wartime aircraft availability.

Two scenarios were used in the models described in this chapter:

- o A "steady-state" program with level flying activity on each day of a 90-day period.

- A "square wave" program that assumed a 30-day Indian Ocean contingency followed by transition to a NATO war.

These scenarios were based on planning information obtained from the Navy. Although the steady-state scenario does generate programmed flying hours for each of the aircraft considered in the study, it does not contain transients in flying rates that can have a significant effect on maintenance backlogs, repair generations, and supply stockage position. The second scenario, which envisions periods of standdown followed by periods with higher-than-programmed flying activity, generates the same flying hours over a 90-day period as the first but also includes transients in pipeline assets.

In both cases the component removals and demands for resupply are the same when averaged across a time span of about 45 days. The primary difference is that aircraft maintain continuous activity at programmed sortie rates in the steady-state scenario, whereas the dynamic scenario has periods of high activity followed by periods of no activity In the former case the aircraft must be maintained in a state of high availability at all times, whereas in the latter case the availability needs vary depending on the activity rate. If a set of resources can support the sustained steady-state rates, they should also be able to support the dynamic flying rates. Conclusions drawn from the steady-state scenario were tested in the long-term dynamic scenario.

The effects of an interruption in the resupply pipeline to the carrier were also considered for both scenarios. These excursions permitted evaluation of the protection afforded by the carrier's self-sufficiency stock under a variety of different stockage policies.

The possible effects of aircraft attrition on the demand for logistics support were not considered because combat losses were assumed to be replaced by "filler" aircraft. Of course, if attrition reduced the total aircraft inventory to the point that filler aircraft were not available, support requirements would be reduced accordingly. In this sense, the scenario generates a conservative (high) estimate of likely demands for support.

THE CABAL DATA BASE

As is common in studies of this type, a great deal of the study effort was devoted to development of a data base describing characteristics of the components to be considered in the analysis. The aircraft were the F-14A, S-3A, E-2C, and three A-6 variants. Since the study was to concentrate on avionics equipments, the set of components was initially based on the Avionics Equipment Configuration List (AECL) for the deckload carried by the USS CONSTELLATION on her 1978 WESTPAC deployment.

When it became apparent that a component list based on the AECL did not include many of the components that generate workload in avionics work centers,[1] the data base was expanded to include these items. Demand and repair data for these components were extracted from 3M reports and the data base was augmented with information on test equipment and skill requirements, depot repair time, and other item characteristics from a number of different sources.

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[1] That is, workload reported through the Navy's Maintenance and Material Management (3M) system showed other components being repaired in the work center.

The data describe the configuration of aircraft and components, historical removals and BCM rates, repair times including scheduling, processing, and hands-on repair durations, test equipment requirements, manhour requirements, and so forth. The 3M failure and repair data used in the study reflect fleet-wide experience for the period 1 July 1978 through 30 June 1979. More recent data were available, but data reporting problems associated with implementation of the Subsystem Capability Impact Reporting (SCIR) system made these data suspect. Navy representatives thus advised use of data from the earlier period to minimize data quality problems.

Component-specific data, and indentured relationships between components extracted from the Aviation Supply Office (ASO) weapon system file[2] were used for a variety of statistical analyses to describe peacetime performance of the aircraft material readiness support system. They were also used in conjunction with scenario data for the modeling described below.

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[2] Indentured relationships describe the application of subcomponents to their next higher assembly, i.e., the set of parts that make up the component exchanged at the aircraft. The component list considered in the study was constrained by the component configuration data contained in the Weapon System File (WSF). For the cases in which these data were incomplete, the component set was artificially reduced. The comparison of actual and predicted number of components awaiting parts discussed in Chap. IV indicates that WSF configuration data deficiencies were not severe. Furthermore, since the study developed a relative comparison of alternative policies, WSF data problems (which would affect all alternatives) should not affect the ordering of alternatives. Assuming that such problems are randomly distributed across components in the WSF, the comparisons discussed in this Note provide conservative estimates of the magnitude of differences among alternatives because the level of protection for critical items is higher for the alternative than current policies.

MODELS EMPLOYED IN THE SUPPLY ANALYSIS

Two primary models were developed and used in various parts of the supply and transportation analysis:

- A model of the logistics support process for evaluating the effects of policy options on measures of wartime aircraft availability.
- A stockage requirement model used to emulate the ASO process for generating Aviation Consolidated Allowance Lists for carriers and Naval Air Stations.

A version of Rand's Dyna-METRIC [Refs. 4, 5] model was the primary analytic tool used during the study. This model, an analytic representation of the aircraft support system, avoids four major limitations of current resource requirements methodologies (and most other models of the support system). Dyna-METRIC explicitly:

- Focuses on weapon-oriented performance measures (such as aircraft availability and sortie generation).
- Considers cannibalization[3] as a source of supply.
- Accounts for the transients in support system performance associated with variations in the level and intensity of operations.

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[3] Mission-critical demands that cannot be satisfied from stock can be met by cannibalization--the use of parts from systems down for other resources--or by expedited repair of components already in the maintenance pipeline. Traditional measures of supply performance show degradation even when these alternative sources are able to meet the material requirement. The contribution of cannibalization at both the WRA and SRA level to operational performance will be discussed further in Chap. IV.

- o Deals with the interdependencies among resources and functions that characterize the support delivery process.

The model is based on the pipelines concept outlined in the Introduction (see Fig. I-1) and uses an extension of Palm's theorem for the stochastic properties of the demand, repair, and resupply processes. In addition, it can examine the effects of resupply or repair interruptions, alternative logistics support structures, claims by more than one aircraft type on a common resource pool, and demand distributions with a variance-to-mean ratio greater than one (compound Poisson processes).

Dyna-METRIC requires four classes of input data:

- o A scenario that describes the support structure, the flying program by day of the conflict, and unusual states of the support system, such as transportation cutoff.
- o Component data describing the demand rate, maintenance turnaround time, beyond capability of maintenance fraction, resupply time, and characteristics of the demand distribution.
- o Resources available to the system, including stock, manpower, and test equipment.
- o A description of the relationships among components, and between components and repair resources.

The version of Dyna-METRIC developed for the Navy uses only the first three classes. Due to the size of the study's data base, the fourth class was handled by a series of pre-processors which generate AWP projections for indentured components and for simulating the repair

process. As will be discussed in Chap. IV, tests of the models using peacetime flying programs produced results that are quite consistent with the Navy's peacetime experience.

Since it is an analytic model, Dyna-METRIC can compute resource requirements to achieve a specified level of operational performance as well as project performance given a predetermined mix of resources. Because the Navy was concerned that this feature of the model would not accurately reflect current Navy stockage policy, a separate stockage model was developed during the study that approximates the Navy's two-stage AVCAL production process by a single calculation, yielding results that are consistent with those derived from the Navy process[4].

The stockage model, which is described in Chap. III, computes stockage requirements given the demand rate, repair time, BCM rate, and endurance period on the assumption that demands are Poisson. It was also used to "stock" the wholesale supply system. It contains an optimization option which facilitates stockage against an aircraft availability measure rather than a supply effectiveness criterion. The model was used to develop stockage levels for the current system, stockage under a RIMSTOP[5] alternative, and an improved stockage policy; these levels were subsequently evaluated using the Dyna-METRIC model.

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[4] ASO has evaluated the AVCAL approximation, and agrees that it fairly represents the current AVCAL production process [Ref. 7].

[5] Retail Inventory Management Stockage Policy, a DoD program that will change the basis for requirements computation for all of the services [Ref. 15].

EXPLANATION OF PERFORMANCE MEASURES IN THE ANALYSIS

The study shows the results of policy and resource changes on aircraft availability, which is usually described by the terms PMC, FMC, NMC, NMCS, PMCS, NMCM, and PMCM. PMC is the average number of partially mission capable aircraft at a point in time; it is given with respect to a mission type or mission category and represents those aircraft capable of performing those types of missions. FMC is the average number of aircraft fully mission capable and includes only those aircraft capable of performing all missions at a point in time. NMC is the opposite of FMC and therefore includes only those aircraft which are not capable of performing at least one of the required missions. The addition of the suffix S or M indicates that the cause of degraded capability is either supply or maintenance. Aircraft not available for supply reasons are those missing WRAs because of removals and unfulfilled supply requisitions. Those not available for maintenance reasons include aircraft being worked on at the flight line and aircraft undergoing maintenance or periodic inspections on the hangar deck, which may not have component holes.

The measures used in this study are modifications of PMC and FMC because the analysis considers only a subset of components and reasons that aircraft are not available. In this document we will denote these meas es PMCA, FMCA, and NMCA. PMCA is the average number of aircraft available for a given set of missions after aircraft with missing or nonfunctioning avionics are removed, <u>but before loss of capability due to engines, other components, and maintenance is considered</u>. NMCA represents the average number of aircraft which are not capable for any

mission because of avionics malfunctions and is therefore the number of aircraft unavailable due to the subset of components considered in this analysis. Finally, FMCA represents those aircraft which have a completely functioning avionics suite.

III. DESCRIPTION OF THE CURRENT AVCAL AND ITS APPROXIMATION FOR ANALYSIS

PIPELINE DESCRIPTION

Figure III-1 illustrates the current AVCAL in terms of the segments of the repair and resupply pipeline that are protected by spares and the level at which they are protected. There are two categories of spares. Pool or rotatable pool spares replace components in repair or awaiting repair in the shipboard AIMD. Pool requirements are calculated on a component by component basis using a 90 percent fill rate criterion. That is, each component type is provided enough spares to assure that 90 percent of the time a demand for a replacement component can be filled from shelf stock. Since this assures that even when demands exceed the average they can be satisfied most of the time, the components are said to have a safety level. The second category of spares is provided for the attrition (BCM) of components which cannot be repaired locally or are not reparable anywhere (i.e., consumable items). This stock is calculated on a 90-day average BCM or attrition quantity and is sometimes designated "self-sufficiency" or "endurance period" stock since it represents the average number of orders that would be placed in a 90-day period. Both parts of the AVCAL are based on projected wartime removals.

Within the wholesale system spare parts are provided with an average 85 percent fill rate for the average depot repair time. These spares, when available, allow immediate replenishment of orders from the AIMDs. When there are shortages in this wholesale loop a delay is incurred in satisfying BCM or attrition orders. The wholesale spares

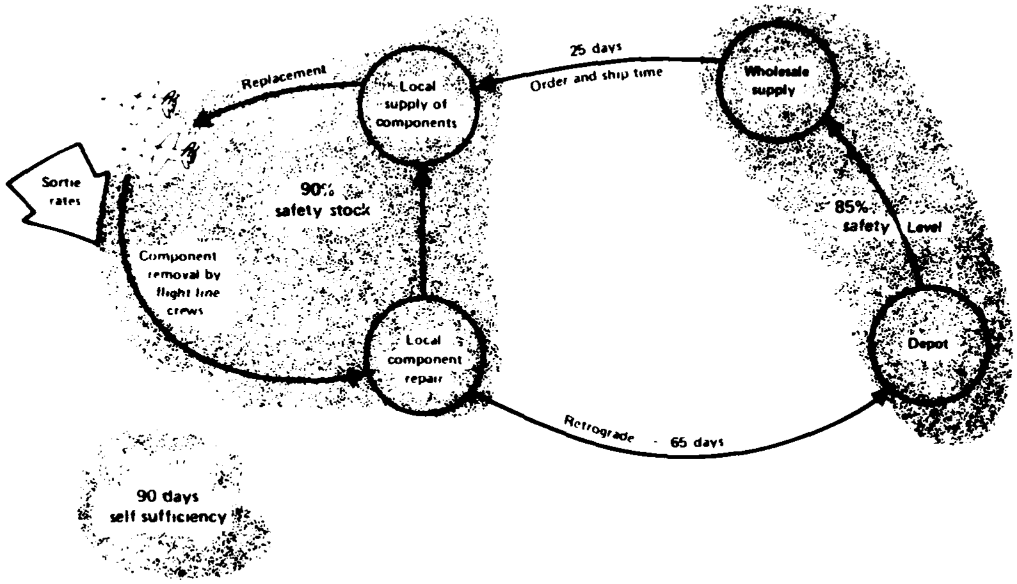


Fig. III-1—Current AVCAL

are not part of the AVCAL but have been included in this discussion because the performance at the ship is intimately tied to the order-filling performance of the wholesale system.

An immediate observation concerning current supply policy (AVCAL plus wholesale supply policy) is that there is no explicit coverage of retrograde and order and ship (O&ST) pipelines. Figure III-2 shows the effective coverage of the AVCAL. After some period of time most of the self-sufficiency spares will migrate into the retrograde and order and ship pipelines. Even with continuing replacement, at peacetime flying rates for 90 days between one-third and half of the spares will have moved into these pipelines. At wartime flying rates for 90 days all of the self-sufficiency spares are likely to be in the transportation

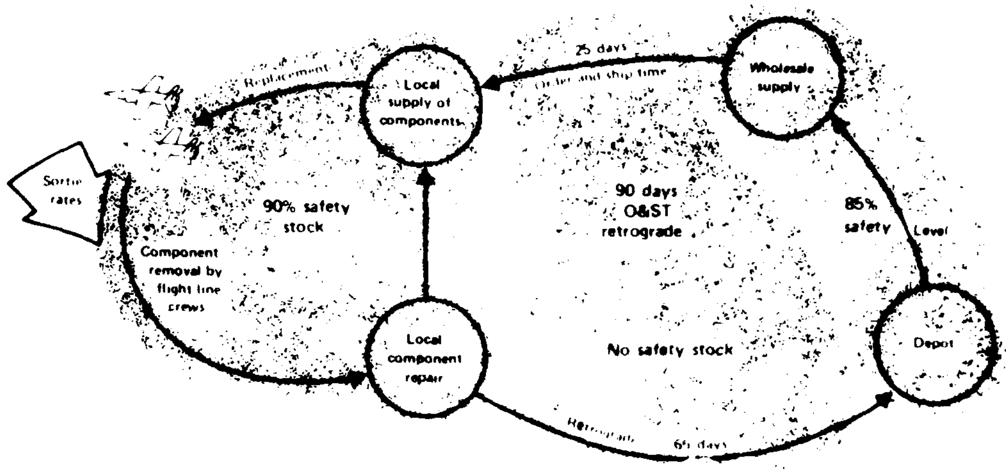


Fig. III-2—Current AVCAL coverage

pipeline, despite ongoing resupply. The carrier therefore has 90 days of self-sufficiency only when it initially deploys. Even then, since the attrition and BCM spares are provided without a safety level, any increase in the mean removal rate can cause shortages before day 90.

A second observation is that the two categories of spares are treated separately in the determination of requirements even though the ultimate aim is a total stock requirement. This practice leads to cases in which neither category shows enough historical demand to warrant stocking under current AVCAL rules--even though the sum of the pipelines would. Thus the AVCAL process may provide zero spares with an overall reduction in protection level.

AVCAL PROCESS DESCRIPTION

The Aviation Consolidated Allowance List (AVCAL) is produced in peacetime through a sequence of steps prior to deployment of a carrier. The AVCAL is developed from tabular reference within an Initial Outfitting List (IOL) which is created at the time a weapon system enters the Navy aircraft inventory and is updated over time. Both the IOL and AVCAL development were approximated in this study, as discussed later in this chapter. Figure III-3 illustrates the combined IOL-AVCAL process and the various inputs to each step.

The IOL provides the quantities of each assembly and subassembly for all aircraft subsystems as a function of ranges of aircraft flying

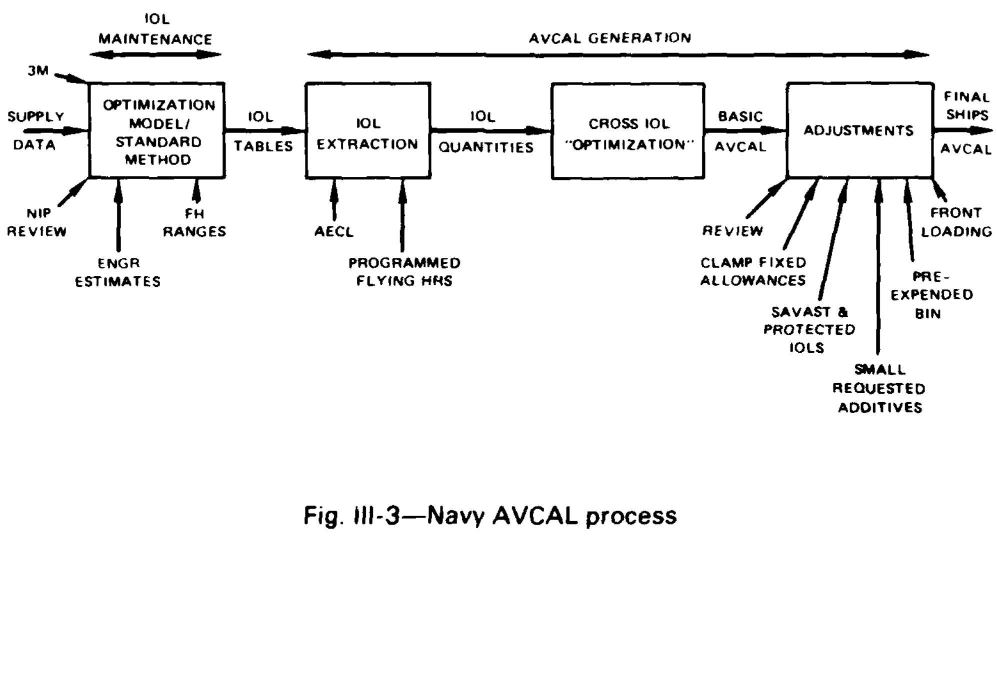


Fig. III-3—Navy AVCAL process

hours. The quantities are divided into two categories, attrition and rotatable pool, which represent stock requirements for components which cannot be repaired aboard ship and components which can be repaired in the shipboard AIMD, respectively. The IOLs are developed as aircraft enter the inventory and are updated annually for front-line aircraft. The initial creation and update of the tables are based on historical demand data (removal rates and BCM rates), repair time data, engineering estimates of demand and repair time (when inadequate historical data are available), and NORS Improvement Program (NIP) reviews. Configuration data, in a top-down breakdown of aircraft into systems, components, and subcomponents, are maintained by the Aviation Supply Office (ASO) and used in the IOL creation/update process.

The IOL tables are initially created by two methods. An optimization model which considers component indenture relationships and minimizes the spares cost of achieving a subsystem backorder rate of .05 has been used for about 10 percent of the aircraft systems in the IOL. The remaining systems have undergone an allowance computation described in Fleet Avionics Supply Office Instruction (FASOINST) 4441.16F [Ref. 13]. The latter procedure <u>updates</u> the spares requirements for all systems in the IOL regardless of the methodology used initially. About 60 percent of the reparable components are included in the Closed Loop Aeronautical Management Program (CLAMP) or other special management programs for which fixed allowances (stock levels) are generated. Fixed allowances override the IOL quantities. They are computed by the FASOINST 4441.16F rules but the data used tend to be more site specific and are reviewed with more care.

An AVCAL for a specific deployment is created through a series of steps commencing about 8 months prior to the deployment date. This amount of time is necessary for the Type Commander (TYCOM) to forward necessary configuration and usage data to ASO, to create and review the various AVCAL computer products, and to order replenishment spares to fill the AVCAL requirement.

One of the early steps is the creation of an Avionics Equipment Configuration List (AECL) by the TYCOM. The AECL indicates which aircraft subsystems will be aboard and the programmed aircraft flying hours to be used in the IOL extraction process (the IOL quantities are based on ranges of flying hours). After the TYCOM provides the AECL, the IOL extraction process (performed by ASO) determines the basic attrition and rotatable pool quantities. For those components which appear in more than one aircraft system there is a step (called "optimization") which divides the quantity in two and then uses the maximum of this quantity and the quantity required for a single system.[1]

The quantities extracted from the IOL tables are subjected to a number of adjustments which attempt to add to and tailor the quantities for a specific deployment. The fixed allowances mentioned earlier, which consider site specific data, override the IOL quantities. (For example, it may be known that a particular ship has a shortage of a certain type of test equipment and therefore has longer repair times than the worldwide average. That ship might be given a fixed allowance quantity larger than the IOL because of the test equipment problem.)

[1] Although the purpose of this step is to take advantage of scale for common components, we were unable to identify either the origin or the logic of the divide by two rule and the term "optimization."

The Ship AVCAL Asset Demand Tape (SAVAST) overrides the IOL attrition quantities when the attrition demands from a previous cruise show a larger requirement than the IOL. The SAVAST may also reduce the requirement to one when there has been no demand on two previous deployments. (For some systems, called "protected IOLs," this reduction is not allowed.)

The TYCOM adds a certain number of spares by "front loading" consumable components purchased from the stock fund. Certain small components costing very little relative to the aircraft subsystems are provided as a Maintenance Support Package (MSP) in pre-expended bins. These items are stocked with spares for an eight-month period. Finally, the quantities provided in an AVCAL are reviewed by the TYCOM, ASO, and other Navy support groups and adjusted based on judgment and additional usage data. [Refs. 1, 12]

APPROXIMATION OF THE AVCAL PROCESS

Several logistics alternatives investigated during the CABAL study required variations of the AVCAL which were impractical to obtain through the normal ASO process. Furthermore, the full programmed scenario flying hours used for the CABAL study were different from any current AVCAL requirements. For these reasons and because investigations of the supply , licy required the ability to separate the AVCAL process into its constituents, AVCALs used in the study were created by approximating the Navy process. Figure III-4 illustrates the approximation.

The rules for the approximation are basically the same as those used for IOL updates for reparable and consumable items. Thus, given

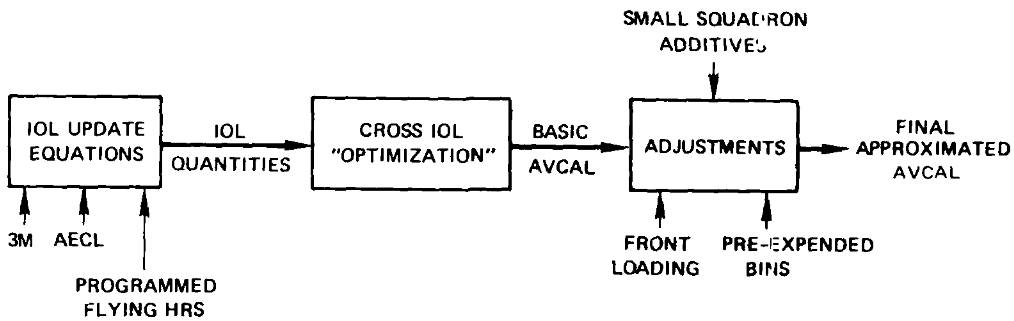


Fig. III-4—AVCAL approximation

the demand history of a component, turnaround time (if it is reparable), and a flying hour program, the process directly determines the IOL quantities applicable to the nominal deckload used in the study. The approximation therefore computes the applicable AVCAL quantity directly without going through the intermediate step of creating additional IOL columns. The update rules are:

1. Stockage of Reparable Components

   a. Non-attrition quantity (rotatable pool)

      The steady-state pipeline, λ_{sr}, referred to by ASO instructions as the Raw Pool Quantity, is first computed using basic data elements

$$\lambda_{sr} + (1 - BCM) \cdot \overline{T}_s \cdot \underbrace{\sum}_{\text{sum across aircraft having this IOL}} \cdot \overline{m} \cdot (\overline{FH} \cdot N_a \cdot QPA)$$

where

$BCM \equiv$ Average fraction of demands which are Beyond Capability of Maintenance

$\overline{m} \equiv$ Average demands per flying hour for one application of this component on a given TMS aircraft

$\overline{FH} \equiv$ Average flying hours per day per aircraft (from operational sortie requirements)

$N_a \equiv$ Number of aircraft (deckload)

$\overline{T}_s \equiv$ Average constrained turnaround time

$QPA \equiv$ Quantity per aircraft in this IOL

The rotatable pool stockage is then given by the variable S_{sr}, which is computed using the following rule:

$$S_{sr} = \begin{cases} 0 \text{ if } \lambda_{sr} \leq .11 \\ k \text{ if } .9 \leq \displaystyle\sum_{i=0}^{k-1} \frac{e^{-\lambda_{sr}} \cdot \lambda_{sr}^{i}}{i!} \\ \text{and } .9 - \displaystyle\sum_{i=0}^{k-2} \frac{e^{-\lambda_{sr}} \cdot \lambda_{sr}^{i}}{i!} \geq \frac{e^{-\lambda_{sr}} \cdot \lambda_{sr}^{i}}{i!} - .9 \\ k-1 \text{ otherwise} \end{cases}$$

Table III-1 shows a sample of this calculation for various values of λ_{sr}. It is identical with the ASO local repair cycle asset level table. This quantity is computed for each subsystem in the nominal deckload as defined by IOL codes. If the component appears in more than one subsystem, the rotatable pool stockage for each is added together to give the total rotatable pool stock for the component.

Table III-1

LOCAL REPAIR CYCLE ASSET LEVEL

If the Rotatable Pool Quantity (RPQ, or λ_{sr}) is:	The Protected Asset Quantity (Stock Requirement, S_{sr}) will be:
0 to .110	0
.111 to .201	1
.202 to .721	2
.722 to 1.342	3
1.343 to 2.016	4
2.017 to 2.727	5
2.728 to 3.463	6
3.464 to 4.219	7
4.220 to 4.991	8
4.992 to 5.776	9
5.777 to 6.573	10
6.574 to 7.379	11
7.380 to 8.194	12
8.195 to 9.016	13
9.017 to 9.844	14
9.845 to 10.678	15

b. Attrition quantity for reparable items

The first step is to determine the steady-state pipeline quantity for the attrition, λ_{sa}, referred to by ASO as the Raw Attrition Quantity. This is given by the equation

$$\lambda_{sa} = BCM \cdot \overline{T}_a \cdot \underbrace{\sum}_{\text{sum across aircraft having this IOL}} \cdot \; \overline{m} \cdot (\overline{FH} \cdot N_a \cdot QPA)$$

where the variables are the same as defined earlier except that

$\overline{T}_a$ ≡ Activity endurance level, and is 90 days for the AVCAL.

Before a spare parts quantity can be computed, the component must pass the set of "entrance rules" given below. Let C_s be the unit cost of the component. The item can be given an attrition quantity when

i. If $S_{sr} > 0$ then λ_{sa} must satisfy $\lambda_{sa} \geq 1$.

ii. Otherwise, if $C_s \geq \$5000$, then λ_{sa} must satisfy $\lambda_{sa} \geq .5$.

iii. Otherwise, if $C_s < \$5000$, then λ_{sa} must satisfy $\lambda_{sa} \geq .34$.

Once the component passes these tests the attrition quantity, S_{sa}, is given by integer rounding.

$$S_{sa} = [\lambda_{sa} + .5]$$

where [] indicates the integer part of the quantity (this gives the .5 rounding rule used by ASO).

If the component is common to other subsystems (IOLs) the attrition quantity of each is added (to give S_{sa}) while keeping track of the maximum attrition quantity for the various IOLs, S^m_{sa}. The final attrition quantity is given by [2]

$$S_{sa} = \text{maximum of} \left\{ \left[\frac{S^T_{sa}}{2} \right], S^m_{sa} \right\}.$$

c. Total quantity for a reparable component

The attrition and pool quantities are added.

$$S_s = S_{sa} + S_{sr}$$

[2] This is the "optimization" step referred to earlier.

2. Consumable Item Stockage

IOL building for consumable items follows the same rules as the attrition quantity for reparable items. The steady-state pipeline, λ_{sc}, is given by

$$\lambda_{sa} = T_a \cdot \underbrace{\sum}_{\text{sum across aircraft having this}} \cdot \overline{m} \cdot (\overline{FH} \cdot N_a \cdot QPA)$$

The item must pass the cost entrance rules first so that a quantity is computed only when

i. If $C_s \geq \$5000$, then λ_{sc} must satisfy $\lambda_{sc} \geq .5$.

ii. Otherwise, if $C_s < \$5000$, the λ_{sc} must satisfy $\lambda_{sc} \geq .34$.

The quantity stocked, S_{sc}, is given by integer rounding.

$$S_{sc} = [\lambda_{sc} + .5].$$

If the component appears in multiple systems the ASO "optimization" rule is applied. By this rule, the quantity of each is added (to give S^T_{sc}) while keeping track of the maximum quantity for the various IOLs (S^m_{sc}). The final consumable quantity is then given by

$$S_{sc} = \text{maximum of } \frac{S^T_{sc}}{2}, S^m_{sc} .$$

DEVIATION OF APPROXIMATE AVCAL FROM ASO-GENERATED BASIC AVCAL QUANTITIES

When the above rules are applied, the IOL quantities and resulting total quantities of spares should match the quantities found in the ASO IOL tables and in a basic ship's AVCAL (the AVCAL before SAVAST updates, review, and front loading). Deviations should be attributable only to differences in (i) data elements, (ii) configuration, and/or (iii) fixed allowance quantities. The data element differences are primarily due to the study's use of worldwide average demands, flying hours, turnaround times, BCM rates, etc., for a time period different from that used by ASO in generating the IOLs and in determining the basic AVCAL (and when the IOL quantities are based on engineering estimates). Configuration data in the CABAL study differ from those in the IOL since consumable item configuration data in the IOL are not kept up to date by ASO. Fixed allowance deviations will occur not because of process rules but because of changes to data elements resulting from the CLAMP review process. The data elements used in the CABAL analysis will differ somewhat from those elements that have been altered in the review process.

One other source of difference lies in the use by ASO of IOLs generated by the indentured optimization model and which have not been updated by the rules given above. This was true for about 10 percent of the aircraft systems at the time of the CABAL study.

APPROXIMATION OF SAVAST, FRONT LOADING, AND OTHER ADJUSTMENTS TO THE AVCAL

A number of adjustments and additives to the AVCAL modify the stock requirements prior to a deployment. Some of these adjustments are based on previous cruise data, some on a desire to improve stockout protection for small squadrons, and some on the judgment of TYCOM and other personnel. The SAVAST update, as mentioned earlier, is an adjustment for consumable items and the attrition portion of reparable item stockage based on previous cruise data. Basically, the rules in a SAVAST update are:

1. If the average monthly demand on SAVAST is greater than zero, then the AVCAL quantity is set to the maximum of three times that demand and the basic AVCAL quantity.
2. If the average monthly demand is zero, the basic AVCAL quantity is greater than zero, and the system the component belongs to is not IOL protected[3], then the quantity is set to one.

This update is important in preparing for a deployment because of data problems surrounding consumable items in the IOL tables. However, because the data base for AVCAL generation and evaluation did not include specific cruise history, and because the configuration of consumable items was up to date, it was not necessary to include the SAVAST step in the AVCAL approximation (three times the average monthly demand was the stockage requirement by the normal AVCAL rules)

Small squadrons with four or less aircraft (the E-2C in this study) receive an upward adjustment to the basic AVCAL quantity to increased the stockage range. For those components unique to the aircraft of the

[3] Some systems are protected from SAVAST stock reduction.

small squadron the quantity of spares is set at a minimum of one. This avoids the likelihood of many items being given zero as a requirement just because the flying hour level of the small squadron does not generate enough demand to warrant stockage under the usual AVCAL rules. This adjustment was made in the CABAL AVCAL approximation for the E-2C components.

The Maintenance Support Package (MSP) is provided with eight months of demand of consumable components in pre-expended bins. Although it was not possible in our data base to identify these components, the approximation used items costing less than $100 as a surrogate and provided them eight months worth of stock. Thus the depth of stock for the small number of items meeting this cost threshold was increased over that implied by direct application of the AVCAL rules.

TYCOM front loading is a method of increasing the range of components stocked based on TYCOM expenditures for additional components. The rules and level of expenditure vary by TYCOM and time period but the primary objective is to provide at least one spare for those components which have shown some history of failing but do not receive spares by other AVCAL rules and adjustments. The study selected those consumable components costing less than $5000 as candidates for front loading and provided a stock level of one for each which showed some demand during a previous year in the CABAL data base. These adjustments significantly increased the range of stockage without much increasing the AVCAL cost.

There was no approximation to the AVCAL review process.

COMPARISON OF APPROXIMATE AND ACTUAL AVCALS

There are a number of reasons why specific quantities of spares in the approximation can deviate from an actual AVCAL tape, but the most significant ones are data differences between those used in the study and those used to create real AVCALs. As mentioned, up-to-date configuration and demand data for consumable items are not reflected in the IOL tables and therefore, since the study has more up-to-date data and derives its AVCALs directly from that data, there are differences in the basic AVCAL quantities. Comparison of the approximated IOL quantities with tabular reference in the ASO IOL under the same flying hours indicated about the same depth and cost for those components given a stockage level greater than zero and showed slightly more consumable components stocked in the IOL tables, apparently due to the configuration and demand errors mentioned above. A cost comparison of the approximation and IOL reference for basic AVCAL quantities showed the S-3A total cost about 10 percent higher in the approximation and less than 1 percent different for costs associated with the F-14A. The increased S-3A costs were apparently due to recent increased demand data for S-3A WRAs. The IOL update rules used in the approximation were checked and verified by ASO (see Ref. 7) for consistency with their rules.

The cost of avionics components in the approximate AVCAL based on the CABAL scenario and data was about $49.8 million, compared with a cost of $48.4 million for avionics components in a previous USS CONSTELLATION deployment. Since the study did not include the A-7 aircraft, the approximate AVCAL cost is higher. However, the

CONSTELLATION AVCAL costs on uninflated component costs and on a significantly lower flying program for the S-3A. When these factors are considered, the costs are quite close.

Another test of the AVCAL approximation was performed in conjunction with a test of the Dyna-METRIC prediction of AWP. The model was run with the CABAL data base and AVCAL approximation to predict the AWP time that might occur at peacetime flying rates. A comparison with actual peacetime AWP times indicated a very close approximation to the peacetime rates and gave further confidence that the combination of model, data base, and supply policy approximation was accurate enough to evaluate the logistics policy options considered in the study.

APPROXIMATION OF WHOLESALE SUPPLY POLICY

A myopic view of the wholesale system considers only the current order and shipping time (O&ST) delay for attrited components. This view does not allow for variation in the delay due to increasing shortages in a wartime environment, capacity bottlenecks within the depot repair system, and transportation interruption. The CABAL study, although it did not consider depot repair capacity issues, did attempt to reflect the possible wartime changes in O&ST due to increasing wartime demands and the wholesale supply policy. The Dyna-METRIC model created the O&ST based on retrograde transportation time, current depot repair time, wholesale supply policy, and outbound transportation time. Figure III-5 illustrates the process. Average quantities of each component in the retrograde pipeline and depot repair pipeline are compared with the wholesale stockage level to obtain an average backorder and/or shortfall within the wholesale system. A portion of this is allocated to the

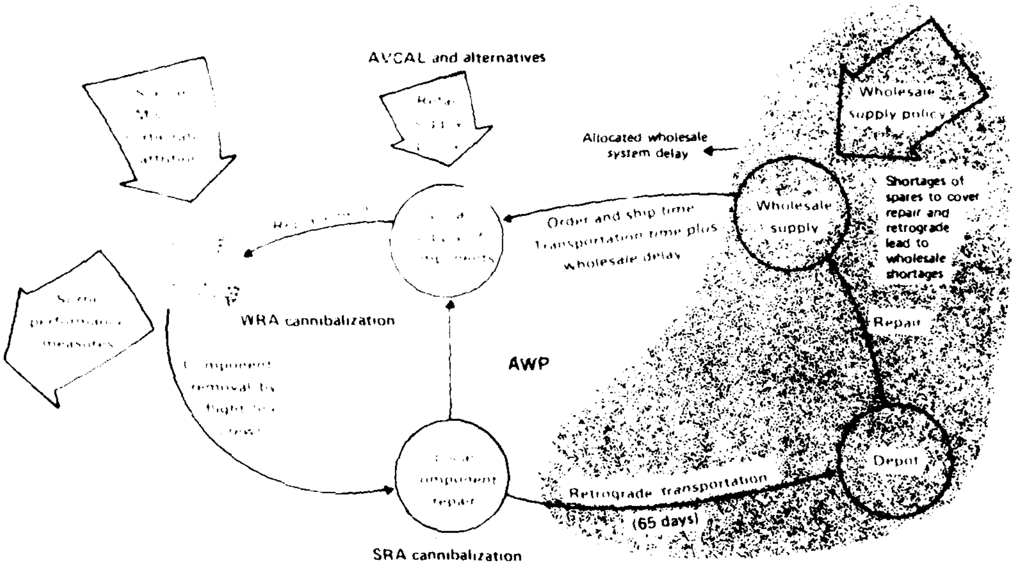


Fig. III-5—Wholesale delay

carrier based on its relative demand for components. The allocated shortfall represents the quantity of components for which orders are delayed and cannot be fulfilled immediately (and placed in the outbound transportation pipeline). This quantity plus those already in the outbound transportation loop represent the total (not available to the ship) in the order and ship pipeline.

The current wholesale policy provides spare parts for the average peacetime depot repair time using the variable safety level (VSL) method to achieve an 85 percent average fill rate (an .85 probability that a component can be supplied from shelf stock when one is ordered). The CABAL study did not use the VSL methodology but did create a wholesale stock requirement based on an 85 percent fill rate criterion for each

component. Since VSL minimizes cost, it is more likely that that process will create spot shortages as expensive components are slighted in favor of cheaper ones in achieving the average fill rate objective. The wholesale approximation used by CABAL will thus show a higher level of protection on certain expensive WRAs. However, it was felt that this approximation was accurate enough to reflect the effect of the wholesale variation in O&ST on the various logistics alternatives investigated. This was supported by tests of the entire model, data, and supply policy in predicting peacetime AWP times.

VI. PERFORMANCE OF THE CURRENT LOGISTICS STRUCTURE UNDER THE CURRENT SUPPLY POLICIES

The DRMS suggested that low peacetime aircraft availability was a major problem and that part of the cause was the small size of carrier squadrons coupled with existing stockage, maintenance manpower, and test equipment requirements policies. This chapter gives the results of a more recent analysis of current supply requirements policies and their potential effect on wartime aircraft availability. DRMS indicated that AWP was an important factor limiting availability. The supply analysis in this chapter considers some of the additives and adjustments to the basic AVCAL as well as the effect of well-managed SRA cannibalization on AWP and aircraft availability. It also considers the possibility of reducing AWP time through a larger shore-based repair facility. The effect of cannibalization of WRAs at the flight line on projected aircraft availability under current supply policy is also discussed.

SUPPLY ANALYSIS: THE DYNA-METRIC MODEL

The Dyna-METRIC model [Refs. 4, 5] was used to determine the potential improvements in aircraft availability resulting from alternative supply policies and logistics options. Figure IV-1 shows the various parts of the logistics structure in the Dyna-METRIC model. Local repair and resupply of aircraft components (WRAs) for the flight line are modeled in detail. Scenario-driven missions and sortie demands, combined with historical rates of component removal at the flight line, provide the basis for component repair requirements in the shipboard AIMD. Removals by the flight line crews also create a demand

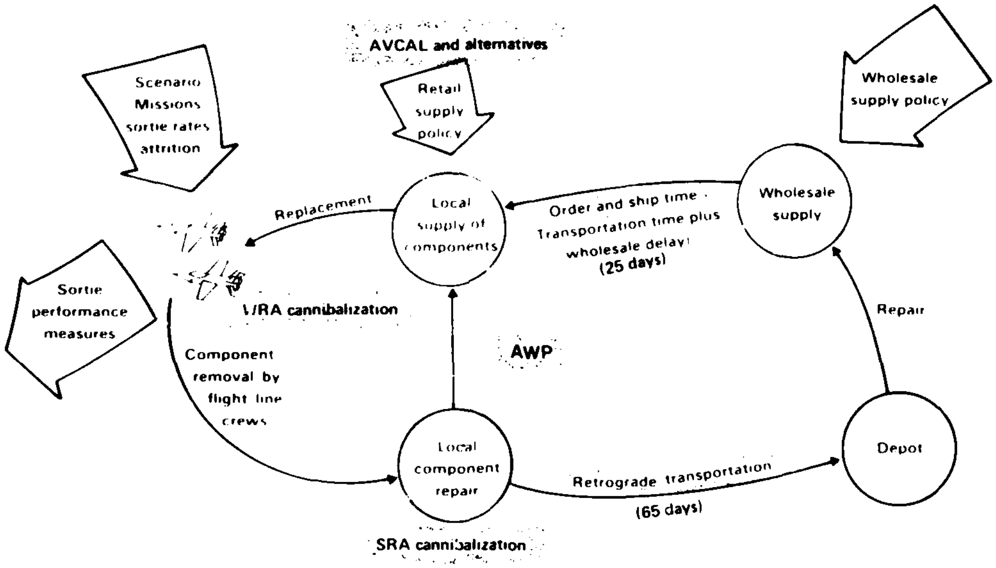


Fig. IV-1—The representation of supply and related logistics resources in the Dyna-METRIC model

against the shipboard supply system to provide a serviceable WRA for the aircraft. When the supply system cannot provide the requested spare part the component is backordered, in effect creating a "hole" in an aircraft. These holes or shortages of WRAs can be consolidated at the aircraft through the process of WRA cannibalization. Dyna-METRIC has been used to show the resulting aircraft availability with and without WRA cannibalization. The shipboard supply policy (which determines the quantity of spare parts) and the amount of WRA cannibalization (which moderates the effect of shortages on aircraft availability) are two important aspects of shipboard component repair and replacement measured by Dyna-METRIC.

WRA repair may require the repair of one or more SRAs. Repair of SRAs (subcomponents) is another aspect of the shipboard AIMDs modeled in Dyna-METRIC. The shop repairing the WRA generates both a removal of an SRA and a demand against the supply system for a spare serviceable SRA to replace it. Inability to provide a spare SRA causes a backorder against that subcomponent and an Awaiting Parts condition for the WRA. The WRA is then sent to an AWP locker until the appropriate SRA becomes available through SRA repair or resupply. When two or more WRAs are in AWP condition for different SRA backorders, the holes in WRAs can be consolidated by SRA cannibalization. Dyna-METRIC was used to evaluate SRA supply policy options as well as the effect of SRA cannibalization on AWP and its resulting effect on aircraft availability.

Certain types of repairs cannot be performed on the ship and must depend on retrograde transportation (currently about 65 days) to a depot repair facility. At the time a WRA or SRA is determined to not be reparable aboard ship an order is placed with the wholesale supply system. If the wholesale system has a serviceable component available immediately, there is still a transportation delay (currently about 25 days) in moving the component to the ship. When the wholesale system cannot provide the component, there is an additional order and ship delay while the component is backordered. Dyna-METRIC was used to develop an estimate of the wartime O&ST delay given historical depot repair times and a wholesale supply policy for component spares.

The supply analysis made certain assumptions about the availability of resources for shipboard component repair and for depot component repair. Average historical repair times were used to represent the

projected average repair times, even in a wartime environment. The CABAL maintenance analysis [Ref. 9], however, indicated potential wartime overloading of the Versatile Avionics Shop Test (VAST) equipment. The degraded availability of the S-3A, E-2C, and F-14A aircraft in wartime due to VAST constraints is not reflected in this part of the CABAL analysis. Thus, the results in this chapter illustrate the effect of policies _after the VAST overloading problem is taken care of_ with one or more of the options discussed in Ref. 9.

All spare parts requirements are assumed fulfilled. Thus, the AVCAL does not reflect shortages and resulting O&ST times due to insufficient wholesale spares procurement. Shortages due to funding or other bars to procurement clearly degrade system performance but are transient and difficult to characterize for policy generalizations. This analysis assumes that funding for spare parts requirements is available and that shortages are due only to random variations of failures about historical averages or due to error in estimation of repair times, transportation times, wartime AWP, and wartime O&ST.

Cannibalization is assumed to be either complete or nonexistent. In the first case, all backorders are consolidated on the smallest number of aircraft (or WRAs in the case of SRA cannibalization). This tends to overstate aircraft availability and capability relative to peacetime experience and less than fully stressed wartime scenarios since only those components deemed mission essential are cannibalized and not all available aircraft are required in those cases. The flight line will probably not exercise the full cannibalization option except in very high sortie rate scenarios with stringent mission requirements.

Finally, it should be kept in mind that this study deals only with avionics components and therefore the effects of other aircraft components (such as engines) are not shown.

These assumptions cause the supply analysis to overstate aircraft availability, especially compared with peacetime availability, when there is no need for complete cannibalization and full mission capability. Comparison of peacetime aircraft availabilities with those currently experienced shows the model predictions to be high for the F-14A (which currently suffers from problems with engines and non-avionic components), high for the S-3A (which currently suffers significant procurement shortages), and fairly close for the E-2C. The results of the supply analysis in this chapter are those that policy and resource changes would have on aircraft which are not dominated by other resource shortages.

The data base used by Dyna-METRIC in the supply and transportation analysis is the same as that used in the maintenance analysis. The data describe the configuration of aircraft and components, historical removals and BCM rates, repair times including scheduling, processing, and hands-on repair durations, test equipment requirements, man-hour requirements, and so forth. The data were based on a one and one-half year worldwide history of removals taken during the 1978-79 pre-SCIR period.

An important aspect of the data used in the analysis is that the supply requirements were based on data elements differing from those used in the Dyna-METRIC evaluation. Supply requirements were created (as they are by the Navy) using constrained repair times and peacetime

AWP times (also constrained). The constraints prevent statistical anomalies from driving the supply requirements too high and the peacetime AWP times are the only data available for estimating AWP. The evaluation runs with Dyna-METRIC used unconstrained repair time data to affect the time to repair so that the supply requirements were in "error." This, of course, also happens on actual cruises, creating a discrepancy between the predicted and actual and leading to shortages of certain components. The Dyna-METRIC model predicts its own wartime AWP times, and they can differ significantly from the peacetime experience. This causes a prediction error similar to that in the current process and potential component shortfalls. Finally, although the supply requirements were based on certain historical averages, the Dyna-METRIC model considered random occurrences about the averages and therefore predicted the effects of deviations from average values. Thus, an important aspect of the supply analysis was that predictions of supply requirements could differ significantly from the needs of a simulated cruise for some of the same reasons experienced on actual cruises.

The model was also tested on its prediction of AWP and component shortages in a peacetime flying program. This tested not only the model's representation of component repair but also the data base of historical removals and the approximation of current AVCAL supply policy. Historical peacetime AWP quantities were determined from the data base by using the historical demand rate, BCM rate, and average number of days of turnaround time in AWP for the set of avionics components considered in the study.[1] The average AWP for a component is then given by

[1] Actual AWP quantities associated with an aircraft may be higher because only the avionics subset of components was considered in our analysis.

$$AWP = DDR_p \cdot (1 - BCM) \cdot T_{AWP}$$

where AWP = Average quantity of components in AWP

DDR_p = Daily demand (removal) rate for a component under a peacetime flying program

BCM = Fraction of removals beyond the capability of maintenance

T_{AWP} = Average number of days of turnaround time spent AWP

Table IV-1 compares model-predicted AWP and the historically measured AWP for the same set of components for the F-14A and E-2C. Note that the total quantity of components in AWP condition, the grand average (average of averages) AWP per component, and the maximum average AWP across components all fall close to the predicted values for that set of components considered in the study. The closeness of peacetime prediction gives confidence that the model and data representation for that part of the logistics system under review are accurate. The

Table IV-1

COMPARISON OF MODEL PREDICTION OF PEACETIME AWP WITH HISTORICAL VALUES

		Total Number of Avionics WRAs AWP	Component Grand Average	Maximum Average AWP
F-14A	Dyna-METRIC prediction	19.7	.08	1.1
	Peacetime experience	18.4	.08	.9
E-2C	Dyna-METRIC prediction	4.1	.024	.23
	Peacetime experience	3.6	.021	.21

analysis of alternative supply requirements methods used requirements methods that differed from the AVCAL processing. These methods are described in Chapter V.

Chapter II characterized the scenario used for much of the analysis. Most of the supply analysis used the "steady-state" wartime scenario to allow easier separation of transient behavior caused by the scenario from the effects of supply policy. In both cases the removals and demands for resupply are the same when averaged across a time span of about 45 days. The primary difference is that aircraft maintain continuous activity at programmed sortie rates in the steady-state scenario, whereas the dynamic scenario has periods of high activity followed by periods of no activity. In the former case the aircraft must be maintained in a state of high availability at all times, whereas in the latter case the availability needs vary depending on the activity rate. If a set of resources can support the sustained steady-state rates, they should be able to support the dynamic flying rates. Conclusions drawn from the steady-state scenario were tested in the more dynamic scenario.

CURRENT STRUCTURE AWP AND IMPLICATIONS FOR REPAIR ASHORE

WRAs frequently await parts for repair due to shortages of consumable components and shortages of reparable SRAs. Currently, a snapshot of the WRAs in local repair aboard ship would show about 50 percent awaiting parts and 50 percent in some stage of repair or awaiting repair. On the average, in peacetime, about 25 percent of the WRAs requiring repair must await repair parts and those that do average about 25 days in the AWP state. Furthermore, those components which

become AWP require about 50 percent additional elapsed maintenance time and man-hours to repair. Clearly, the current system pays a high price for AWP in terms of available WRAs, turnaround time, and maintenance man-hours (plus the AVCAL cost for additional WRAs to cover the incidence of AWP--about $11 million[2] per carrier for the avionics components in the study). Wartime AWP quantities and times are likely to greatly exceed those experienced in peacetime because the AVCAL, provided to support wartime flying rates, permits significant AWP rates even at peacetime flying rates.

The DRMS observed these costs and hypothesized that a larger scale AIMD such as one ashore supporting several carriers would be more likely to generate demands to warrant more complete stocking of repair parts and therefore reduce the WRA AWP quantities. Furthermore, the larger scale would provide more opportunities for SRA cannibalization (consolidating repair parts shortages when several similar WRAs are AWP for different subcomponents).

We first evaluated the effect of AWP on aircraft availability at wartime flying rates. We then examined the effect of certain AVCAL stock additives not considered in the DRMS. Finally, we examined the role of SRA and WRA cannibalization in mitigating the effect of AWP on aircraft availability.

Wartime AWP was projected by Dyna-METRIC by using the scenario to determine SRA and repair part removals, comparing need for replacements

[2] This figure was derived by computing the AVCAL with the AVCAL approximation and using constrained turnaround time excluding the constrained AWP time. That is, the modified constrained turnaround time was computed by summing the constrained processing, scheduling, and repair components of turnaround times, excluding the AWP portion, and limiting the total to 20 days as done currently.

of these with supply quantities, projecting shortages, cannibalizing where possible, and using configuration data to relate subcomponent shortages to the number of WRAs in AWP. One option in the model was to disable this processing of subcomponents and show the aircraft availability when no AWP was present. Table IV-2 shows the effect for the E-2C, S-3A, and F-14A. Note that the AWP effect, although significant in some cases, is moderated by WRA cannibalization. Clearly, with well-managed SRA cannibalization and with the AVCAL range additives, AWP is not the only aspect of component repair and supply policy which is dominating performance. Chapter V on supply policy alternatives will show ways to further improve aircraft availability.

The model results presented in Table IV-2 include the effects of additives developed using the approximations described in the previous

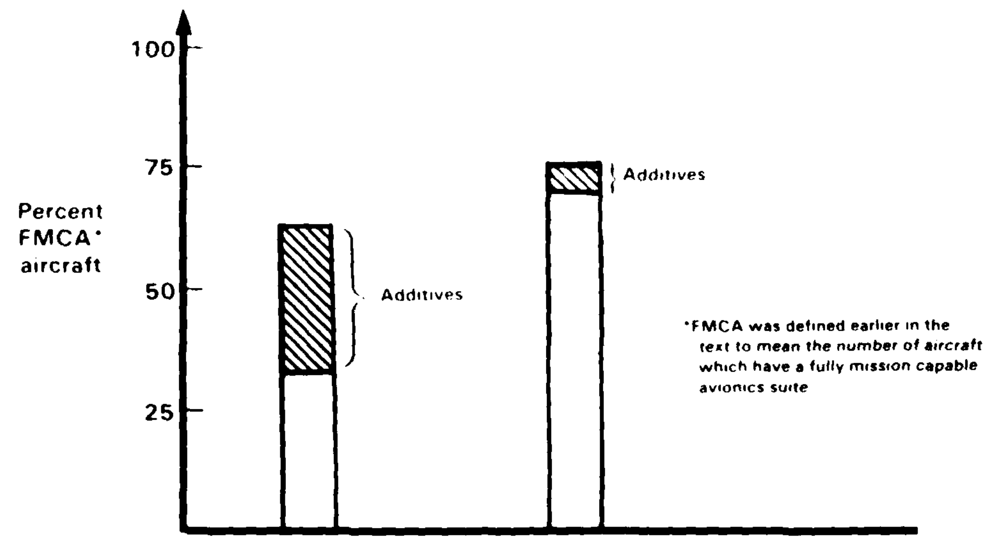
Table IV-2

EFFECT OF AWP ON AIRCRAFT AVIONICS AVAILABILITY
(Percent FMCA)

	Day 30 of Constrained Wartime Flying Program					
	F-14A		S-3A		E-2C	
	WRA Cann	No WRA Cann	WRA Cann	No WRA Cann	WRA Cann	No WRA Cann
Without AWP	93	69	83	47	70	44
With AWP	90	58	79	36	68	38
	Day 90 of Constrained Wartime Flying Program					
Without AWP	92	64	77	37	67	36
With AWP	89	52	74	24	64	38

chapter. These additives, not considered in the DRMS, increase the cost of the AVCAL and reduce the AWP in the current air logistics structure.

AVCALs created with and without these additives were input to Dyna-METRIC and compared under the wartime steady-state scenario. Figure IV-2 illustrates the cost and effect of these additives on aircraft availability in the current structure. The effect is most dramatic on the E-2C, which gets a small squadron additive. Although the relative cost of these additives for the small squadron is quite high, they provide considerable protection against uncertainty in demand prediction due to the poor quality of removal history for consumable items. Despite the resemblance to a "patch" on the supply policy, the additives appear to be a cost-effective technique for reducing AWP.



Cost (millions)	E-2C	S-3A
No additives	3.2	19.8
Additives	6.7	20.2

Fig. IV-2—Costs and effect of AVCAL additives on aircraft availability — day 90 of scenario

The previous chapter mentioned the effect of SRA cannibalization on aircraft availability. Figure IV-3 shows this effect in combination with the AVCAL additives. The aircraft availability is improved (about 40 percent for the E-2C and 17 percent for the S-3A) and for the S-3A is about the same availability improvement projected for the shore-based repair option in the DRMS. It should be noted, however that effective SRA cannibalization and AWP reduction require a very cooperative maintenance-supply interface. It probably requires enhanced data collection and management to maintain high visibility of current AWP conditions, the potential for cannibalization, and the value of reducing certain WRA shortages to increase aircraft availability.[3]

We examined the potential to reduce AWP through the DRMS shore repair option by determining the subset of WRAs which had projected AWP times so large in the wartime scenario that it was worthwhile to incur the transportation times and move them ashore. Under the current 90-day average round-trip transportation times and under the optimistic assumption that AWP times ashore would be near zero, hardly any components showed improved total processing time.

We repeated this analysis for a 50-day round-trip transportation time and found that only a few additional components benefited from the shore repair option. The conclusion is that under current transportation limitations and considering only AWP without increasing the cost of <u>carrier</u> stockage, very few items would improve aircraft availability if moved to shore repair. Had there been manpower savings by moving repair ashore it would have been possible to obtain additional

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[3] The Naval Aviation COmmand Management Information System (NALCOMIS), currently under development, could provide a mechanism for managing AWP.

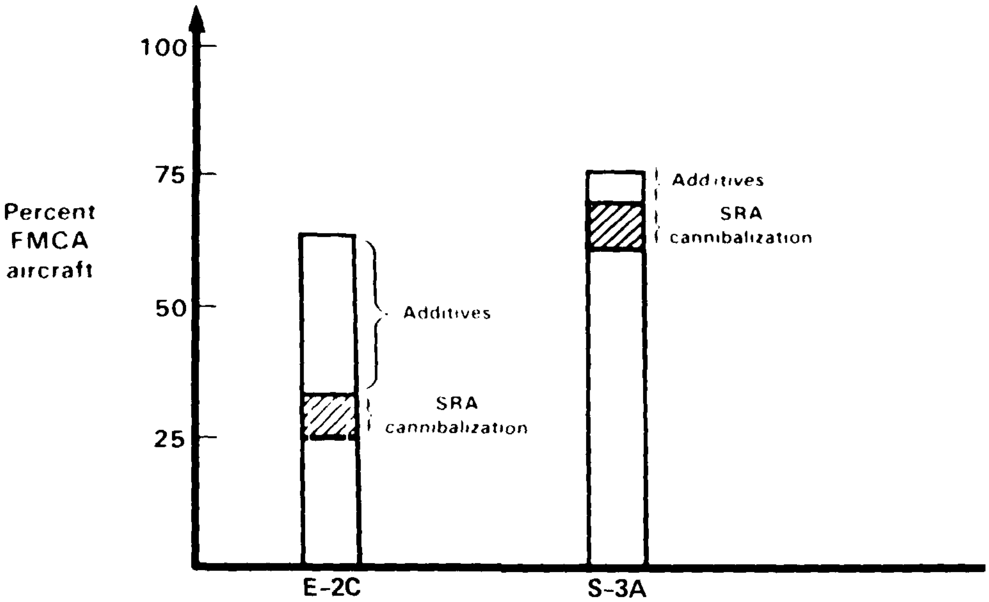

Fig. IV-3—Effect of SRA cannibalization and AVCAL additives on aircraft availability — day 90 of scenario

stock to cover the increased pipelines and maintain an overall constant cost.

Figure IV-4 shows relative aircraft availability when WRAs are completely cannibalized to reduce all shortages to the fewest number of airframes and when no cannibalization is performed. In all cases SRA cannibalization and AVCAL additives are assumed. The large difference between the cannibalization extremes indicates that a high level of WRA cannibalization is required to maintain reasonably good aircraft availability. This comes at a cost in manpower, reduced flexibility to cover other shortages, and increased breakage as more components are removed and handled. Chapter VI examines some supply policy options to improve aircraft availability and reduce the cannibalization requirements.

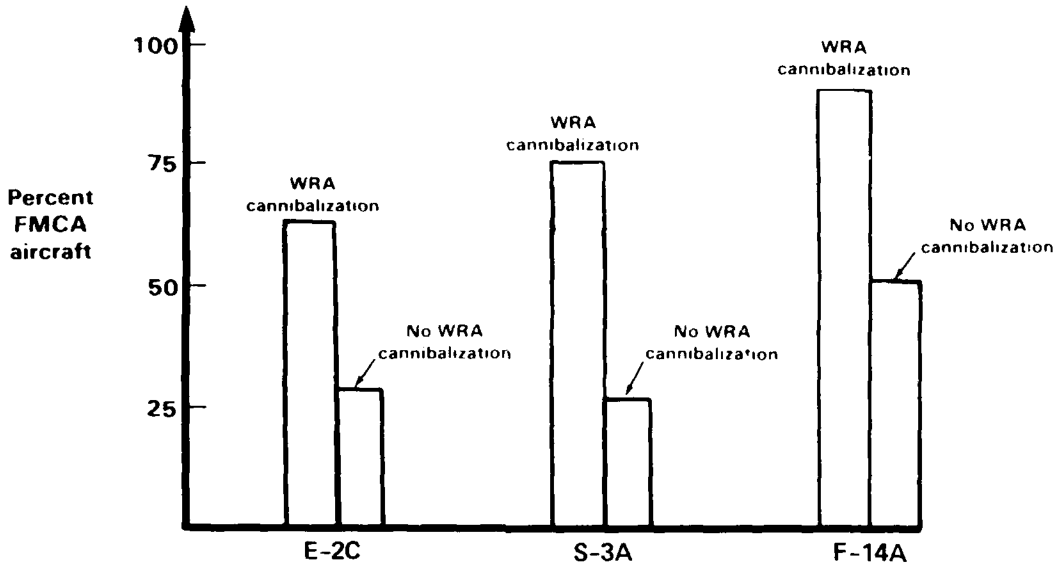

Fig. IV-4—Effect of WRA cannibalization on aircraft availability

There are two additional issues regarding the analysis which must be addressed. First, the results under the steady wartime flying program scenario and the Indian Ocean/NATO scenario with its intervals of high and low flying activity must be compared. Table IV-3 shows the S-3A FMCA rates with the steady-state flying program at points immediately preceding and immediately following high activity in the IO/NATO scenario under policies of full and no cannibalization of WRAs. It can be observed that the aircraft availability is a little better preceding the activity and a little worse afterwards but not enough to bias the results of the study.

Table IV-3

FMCA RATES IN IO/NATO SCENARIO VERSUS RATES FROM THE AVERAGE FLYING PROGRAM (Percent)

	Day 69 Immediately Preceding High Flying Activity		Day 77 Immediately After High Flying Activity		Day 90 Average Flying Day	
	No Cann	Cann	No Cann	Cann	No Cann	Cann
Steady weapon flying program	--	--	--	--	25	76
IO/NATO	22	71	26	82	--	--

The second issue is the relationship between FMCA and PMCA. That is, is aircraft availability improved when only partially mission capable states are considered? A *mission-essential* subset of avionics components for a level C mission capability[4] for the E-2C was determined from SCIR requirements.[5] This reduced the number of components by 20 percent. Table IV-4 shows the PMCA percentage versus the FMCA results for the E-2C and F-14A. It is clear that the FMCA measure is not much different from the PMCA measure for the set of components considered in the study.

[4] The SCIR system Level A requires that all aircraft subsystems be operational for full mission capability. An aircraft reported at SCIR Level C can perform all but two of its potential missions.

[5] This determination was somewhat judgmental since there is not a one-to-one correspondence between avionics WRAs and the system descriptions in the SCIR list. In particular, degraded modes of some systems were difficult to identify with specific components. For those systems required for level C mission capability, we assumed that the entire system was required.

Table IV-4

PMCA VERSUS FMCA--DAY 90 OF SCENARIO

	PMC			FMC		
	No. WRAs	Cann	No Cann	No. WRAs	Cann	No Cann
E-2C	138	65%	35%	173	64%	29%
F-14	202	90%	57%	235	90%	52%

SUMMARY OF FINDINGS: RANGE ADDITIVES AND CANNIBALIZATION

AVCAL range additives and SRA cannibalization significantly reduce AWP time and improve aircraft availability. The additives improve availability by increasing the range of components stocked and therefore provide increased protection from demand prediction uncertainty. SRA cannibalization, while important, requires considerable management and an effective maintenance-supply interface.

The S-3A availability improvement through range additives and SRA cannibalization is about the same as that predicted for the shore repair alternative in the DRMS. As a result of changes in stockage policy since DRMS, additives that were not considered in the DRMS, and the potential to improve AWP by SRA cannibalization through effective management, significant gains can be made within the current logistics structure.

With the AVCAL additives, SRA cannibalization, and current transportation times, few components have AWP times long enough to warrant moving repair ashore. Assuming no savings in the other

resources (such as manpower and test equipment), a constant cost supply analysis implies that most repair should remain on board the carrier.

Aircraft availability and the amount of cannibalization required are still unresolved. Projection indicates that cannibalization requirements in wartime to achieve even a 75 percent mission capability rate for avionics components are large for most aircraft types. This implies additional work and loss of flexibility and at the same time implies that supply policy is not adequately covering current component removal rates, BCM rates, and AIMD repair times.

Based on these findings, it is recommended that the Navy emphasize and enhance effective maintenance-supply interface for SRA cannibalization and AWP management. Data systems such as NALCOMIS [Ref. 11] should be oriented and extended to improve visibility for management of AWP. We also recommend that the Navy examine alternative supply policy options in light of current aircraft availability and cannibalization requirements. The following chapter describes an initial investigation into supply policy alternatives.

V. ALTERNATIVE SUPPLY POLICIES

An important task of the CABAL analysis was to determine the value of certain improvements to the current logistics structure as an alternative to the shore-based repair alternative. The Navy recognizes that there are shortcomings in the current AVCAL policy and certain extensions have been proposed. For example, in conforming to the DoD RIMSTOP directive 4140.47 [Ref. 15] for secondary item spares, the Navy is developing improved coverage of its resupply pipelines. It is also logical that aircraft availability should be considered directly in supply policy. The AVCAL and its planned extensions are currently based on stockage objectives such as fill rate (percent of the time a requisition can be filled directly from on board spares) and backorders (number of unfilled requisitions). Methods exist which can go beyond these measures and, with very little additional data, determine supply requirements based on desired aircraft availability. This chapter will illustrate the effect of improved stockage policies with and without the aircraft availability objective and compare performance with that projected for the current AVCAL.

SOME COMMENTS ON THE AVCAL PROCESS

The objective of the AVCAL is to create requirements for "enough" of the right set of spare components to cover demands for a forthcoming deployment. As should be, most steps in the process are determined by perceived or experienced demands and are not modified by the reality that some of the requirements cannot be fulfilled due to shortages of components within the Navy. The measure of "enough" has been either a

fill rate objective (in FASOINST 4441.16F) or a system backorder objective (in some of the initial provisioning). The first measures the fraction of demands for spares which are fulfilled immediately and the second measures the number of subsystems short at an arbitrary point in time. Although related to aircraft availability, these measures do not represent the importance of certain component shortages in degrading mission capability. For example, systems with some redundancy are less likely to degrade mission capability than systems which appear on an aircraft once, and for the former a lower fill rate might be tolerated. Also, a 90 percent fill rate for all subsystems (the current rotatable pool objective) can lead to a low aircraft availability when all components are considered. The value of using an aircraft availability objective is shown later in this chapter.

A number of the adjustments to the IOL extraction use "site specific" information. Although there are undoubtedly differences between ships and other sites which cause differing removal rates, BCM rates, and repair times, it is difficult to know whether these differences are transient (random phenomena causing different failure rates, various mix of repair skills, etc.) or recurring. For transient differences it may be better to use worldwide averages or other worldwide parameters (the worst case, for example) to capture the complete range of possibilities.

In testing an approximation to the IOL update process it became apparent that there were some significant differences between the set of subcomponents associated with an aircraft system in the IOL and in the top-down breakdown of aircraft systems maintained in the ASO weapon

systems file. Further checking determined that many of the subcomponents in the IOL are no longer part of the system, or that modifications have created additional variations of the system with different sets of subcomponents which were then added to the IOL, leaving the old subcomponents in also. Thus, IOL extraction is likely to indicate a need for many more subcomponents than are required for a system. Another check of the IOL quantities indicated that consumable item demands are based primarily on initial engineering estimates of failure rather than on current experience. The difficulty of maintaining accurate configuration information and demand data for the thousands of consumable parts has apparently caused the IOL tables to be out of date (for consumable components) compared with current experience. This makes various adjustments (SAVAST, fixed allowances, front loading, etc.) necessary to assure a reasonable match between current needs and requirements. The value of some of these adjustments will be shown later.

The division of demands and requirements processing into attrition and rotatable pool can cause a component which shows demands in each category to not be stocked although the combined need across categories would show a requirement for spares. Furthermore, the variability of need is not considered when the attrition quantity is determined since it is given no safety level. The quantity for attrition is set at the average number of demands over 90 days and does not allow for variability about the average that will cause the demands to exceed the average in many deployments. The attrition pipeline as well as the value of considering the combined requirements of attrition and rotatable pool will be discussed later.

The need for a two-step process in development of an AVCAL might be alleviated by maintenance of more up-to-date configuration and demand data and by implementing the FASOINST 4441.16F equations directly into the AVCAL generation. The IOL maintenance would then be replaced by demand data maintenance and the AVCAL generation would apply the equations directly to the data. This would reduce some of the configuration and demand history errors as well as allow for easier insertion of alternative supply requirements equations. The AVCAL approximation to be described in the next subsection was implemented in this way.

Finally, many of the components in aircraft systems have very little history of demand, either because they are relatively new to the inventory or because they are very reliable. The use of historical data for these components can lead to large errors in estimating averages and possibly inadequate stockage. Certain Bayesian statistical techniques such as the Stein estimation method [Ref. 2] might improve the accuracy of estimates for these low demand components.

COMPLETE PIPELINE COVERAGE

Figure V-1 illustrates the complete, explicit coverage of the transportation and local repair pipelines. All spares for these pipelines are prepositioned on the ship (in a modified AVCAL) and safety stock is provided for the combined requirement. The coverage is similar to the planned extension of the AVCAL for the RIMSTOP DoD directive 4140.47 although the prepositioning of more than 30 days of war reserve retrograde spares is at odds with that directive. Given current transportation times and the likelihood of lengthy resupply

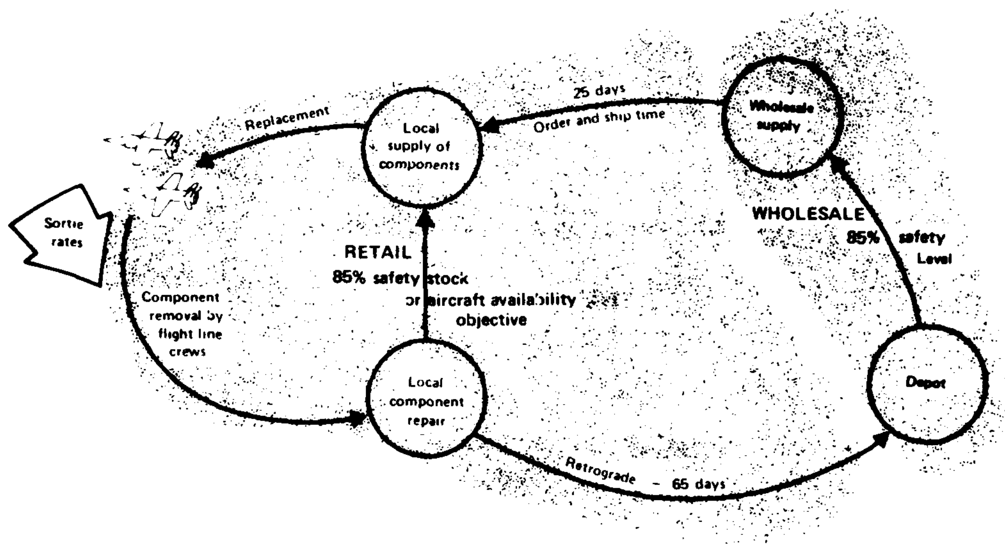

Fig. V-1—Complete pipeline coverage

interruptions, only the prepositioning of the entire retrograde portion was considered. (The only reason for not prepositioning is the cost reduction in safety stock when spares are centrally located for several carriers.)

The pipeline coverage illustrated in Figure V-1 was produced in two ways. The first, consistent with planned extensions to the AVCAL, was to determine a requirement for each component type using an 85 percent fill rate objective. The second method used an aircraft availability objective and tradeoffs between component supply levels to "optimize" or maximize that objective. The optimization process was kept simple to avoid potential implementation problems. For example, the only data beyond that needed in the current AVCAL process are identification of

WRAs (that is, a separation of components into WRAs and others) and identification of components by aircraft type. *It does not* require indenture configurations which tie SRAs to WRAs.[1] The optimization can be performed by setting an AVCAL budget target and maximizing the confidence (probability) of not exceeding a target non-mission capable rate or by setting a target NMCA rate and confidence level and minimizing the cost of achieving it. The technique used in this study was to set the budget target to the current AVCAL value or the extended AVCAL cost from improved pipeline coverage and to maximize confidence of achieving the NMC target. The following subsections describe the rules and equations used for the fill rate objective and optimization.

<u>Rules for Complete Pipeline Coverage: Fill Rate Objective</u>

The steady-state pipeline, λ_{sr}, is first computed using the same basic data elements as the AVCAL process.

$$\lambda_T = (1 - BCM) \cdot T_s \cdot m \cdot \underbrace{\sum}_{\text{sum across aircraft having this system}} \cdot FH \cdot N_a \cdot QPA$$

$$+ BCM \cdot (O\&ST + T_{RETR}) \cdot m \cdot \underbrace{\sum}_{\text{sum across aircraft having this system}} \cdot FH \cdot N_a \cdot QPA$$

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[1] If such data were available, they would be beneficial to the process. However, the problem of identifying specific component configurations and maintaining up-to-date files for each carrier deployment appears difficult for the current supply system and therefore the optimization process only deals with WRAs.

where BCM = Average fraction of demands which are beyond the capability of maintenance

m = Average demands per flying hour for one application of this component on the given TMS of aircraft

FH = Average flying hours per day per aircraft (from operational sortie requirements)

N_a = Number of aircraft (deckload)

T_s = Average constrained turnaround time

QPA = Quantity per aircraft in this system

T_{OST} = Average order and ship transportation time

T_{RETR} = Average retrograde transportation time

The stockage requirement is given by the variable S_T which is computed using the following fill rate rule.

$$S_T = \begin{cases} k \text{ if } .85 \le \displaystyle\sum_{i=0}^{k-1} \frac{e^{-\lambda_T} \lambda_T^{\,i}}{i!} \\ \text{and } .85 - \displaystyle\sum_{i=0}^{k-2} \frac{e^{-\lambda_T} \lambda_T^{\,i}}{i!} > \displaystyle\sum_{i=0}^{k-1} \frac{e^{-\lambda_T} \lambda_T^{\,i}}{i!} - .85 \\ k-1 \text{ if } .85 > \displaystyle\sum_{i=0}^{k-1} \frac{e^{-\lambda_T} \lambda_T^{\,i}}{i!} \\ \text{and } .85 - \displaystyle\sum_{i=0}^{k-2} \frac{e^{-\lambda_T} \lambda_T^{\,i}}{i!} < \displaystyle\sum_{i=0}^{k-1} \frac{e^{-\lambda_T} \lambda_T^{\,i}}{i!} - .85 \end{cases}$$

This is basically the same as the AVCAL rotatable pool rule except that it is applied to the total pipeline and an 85 percent criterion is used rather than the 90 percent factor used in the AVCAL rule.

The small squadron, maintenance support package, and front load adjustments described in the AVCAL approximation were made to the stockage requirement as well after it was determined that increases in stockage range were necessary to improve performance.

Rules for Complete Pipeline Coverage: Optimization with an Aircraft Availability Objective

Although the derivation of an optimization technique using an aircraft availability objective may seem complex, the actual application of the method is not since the rules are only a little more complex than the fill rate objective of the current AVCAL and basically the same data are required. The only additional information is the identification of WRAs and SRAs. The derivation starts with the aircraft availability objective--the probability that no more than k aircraft are non-mission capable.

Under a full cannibalization policy, the probability that no more than k aircraft are not available (due to shortages of the set of components under consideration) is the same as the probability that no more than

$$S_i + Q_i k$$

failures of each component, i, have occurred, where S_i is the supply level for component i and Q_i is the quantity per aircraft of component

i. Let P_N be the probability that no more than k aircraft are not available and let

$$P_i(k/\lambda_i)$$

be the probability of having exactly k failures of component i when the combined average quantity of *i in all* pipelines is λ_i. Then,

$$P_N = \prod_{\text{parts}} \sum_{k=0}^{S_i+Q_ik} P_i(k/\lambda_i).$$

Let C_i be the unit cost of component i. The optimization problem, when operating under a budget constraint, B, is

$$\text{maximize } P_N = \text{maximize} \prod_{\text{parts}} \sum_{k=0}^{S_i+Q_ik} P_i(k/\lambda_i) \qquad (1)$$

$$\text{subject to} \sum_{\text{parts}} C_iS_i \leq B.$$

The optimization problem, when minimizing the cost of achieving a target aircraft availability with a given confidence level, α, is

$$\text{minimize} \sum_{\text{parts}} C_i S_i$$

$$\text{s.t. } P_N \geq \alpha \text{ or, } \prod_{\text{parts}} \sum_{k=0}^{S_i+Q_i k} P_i(k/\lambda_i). \qquad (2)$$

These problems are both solved with the same approach; the only difference is in the stopping rule for the algorithm. The marginal analysis approach compares the marginal gain in the performance measure due to increasing a component's supply level by 1 with the unit cost of the component. The component with the greatest marginal gain per dollar is then given a stock level increase of one, the expenditure is increased by the unit cost, and the marginal gain for that component is recalculated. This process repeats until (1) the budget is exceeded in the case of the budget constrained problem or (2) the performance measure is achieved in the problem with a target performance level.

Marginal analysis has been proven to converge only for problems with separable objectives and constraints, so we have used a trick to make the problem separable. An equivalent problem to (1) is

$$\text{maximize } \log P_N$$

$$\text{subject to} \sum_{\text{parts}} C_i S_i \leq B$$

and an equivalent problem to (2) is

$$\text{minimize} \sum_{\text{parts}} C_i S_i$$

$$\text{subject to: } \log P_N \geq \log \alpha .$$

These are equivalent to (1) and (2) in the sense that stock levels which are optimal for these logarithmic transformations are also optimal for the original problems. Note that we can write

$$\log P_N = \log \prod_{\text{parts}} \sum_{k}^{S_i+Q_i k} P_i(k/\lambda_i) \qquad \text{(nonseparable)}$$

$$= \sum_{\text{parts}} \log \sum_{k=0}^{S_i+Q_i k} P_i(k/\lambda_i) \qquad \text{(separable).}$$

The marginal change in the objective due to increasing the stock level of component i by 1 is

$$\Delta_i = \log \sum_{k=0}^{S_i+Q_i k+1} P_i(k/\lambda_i) - \log \sum_{k=0}^{S_i+Q_i k} P_i(k/\lambda_i)$$

$$= \log \left\{ \sum_{k=0}^{S_i+Q_i k+1} P_i(k/\lambda_i) \middle/ \sum_{k=0}^{S_i+Q_i k} P_i(k/\lambda_i) \right\}$$

$$= \log\left\{ 1 + \frac{P_i(S_i+Q_i k+1/\lambda_i)}{\sum_{k=0}^{S_i+Q_i k} P_i(k/\lambda_i)} \right\}$$

Before stating the steps of the algorithm we note that to satisfy the constraint in problem (2) it is necessary that

$$\sum_{k=0}^{S_i+Q_i k} P(k/\lambda_i) \geq \alpha .$$

Thus, prior to marginal analysis we just increase the stock level of each component until this inequality is satisfied. In problem (1) this is not a first step, but we also point out that marginal analysis can be proven to converge only when the functions are convex (in the integer sense) in addition to being separable. Thus, it is desirable to increase S_i until

$$S_i + Q_i \geq \lambda_i .$$

This will guarantee convexity and hence convergence as well as provide a good nonzero starting point. Finally, note that $P(k/\lambda_i)$ has the following form for a Poisson distribution:

$$P(k/\lambda_i) = \frac{\lambda_i^k e^{-\lambda_i}}{k!}, \quad P(k+1/\lambda_i) = \frac{\lambda_i P(k/\lambda_i)}{k+1}$$

The algorithm steps are:

1. Determine λ_i for each component

$$\lambda_i = \begin{Bmatrix} \text{average in} \\ \text{local repair} \\ \text{loop} \end{Bmatrix} + \begin{Bmatrix} \text{average BCMs/} \\ \text{day X endurance} \\ \text{period.} \end{Bmatrix}$$

2. For problem (1) set

$$S_i = \text{integer ceiling of } (\lambda_i - Q_i k)$$

Do not let S_i go below zero for each component. For problem (2) determine S_i by increasing it until

$$\sum P(k/\lambda_i)$$

for each component. Determine Δ_i for each component where

$$\Delta_i = \log 1 + \frac{P_i(S_i+Q_i k+1/\lambda_i)}{\sum_{k=0}^{S_i+Q_i k} P_i(k/\lambda_i)}$$

Note that the sum in the denominator was determined in step 2 for problem (2). This sum should be saved so that recalculations of Δ_i involve only the addition of the next term to the sum.

3. Find the maximum of Δ_i / C_i across all components and let the index of this component be I.
4. In solving problem (1), see that budget will not be exceeded. If it is, stop. In solving problem (2), see that performance constraint is not satisfied. If it is, stop. Otherwise, go to step 5.
5. Let

$$S_I = S_I + 1$$

and recompute Δ_i. Go to step 3.

Depending on the form of $P(k/\lambda_i)$ it is possible to run into roundoff problems which get in the way of accuracy in computing Δ_i. These roundoff problems can be solved by

a. simply preventing more supply level increases for any component for which

$$\sum_{k=0}^{S_i+k\cdot Q_i} P(k/\lambda_i) \geq .999$$

or

b. using logarithms in the computation of $P(k/\lambda_i)$.

The optimization rule was applied separately to files of WRAs and SRAs. A third file of consumable components was given requirements based on the fill rate objective described in the previous subsection. The algorithm was applied in three steps. First the consumable component requirements and costs were determined. Next the SRA levels were determined using a target NMCA of 1 and desired confidence of .85. The total SRA budget was set at a target equal to the cost of SRAs in the AVCAL for some of the following analysis and was set to the cost of the increased pipeline coverage under a fill rate objective for other parts of the analysis.[2] Finally, the WRA optimization was performed using cost targets from either the AVCAL or the increased pipeline coverage.

Stock levels were determined for aircraft types separately. The approach for common items is to adjust the stockage quantity, after determining the levels separately by TMS, to give the same level of protection. That is, given a stock level S_i associated with an aircraft specific pipeline λ_i, we can determine the protection level, P_i, from

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[2] The results of this computation approximate those that would result from computing SRA stock levels to achieve a target fill rate subject to a cost constraint. While the marginal analysis technique would spread the available dollars somewhat differently from a calculation based on a fill rate criterion, essentially the same results could be realized by establishing consumable and SRA levels to achieve a fill rate objective and performing an optimization at the WRA level.

$$P_i = \sum_{k=0}^{S_i-1} \frac{e^{-\lambda_i}\lambda_i^k}{k!}$$

Then, determine the maximum protection level, P_{max}, across aircraft where

$$P_{max} = \max\ (P_i) \text{ across aircraft}$$

The stock level requirement is then set to that which gives this maximum protection for all aircraft when the total pipeline is considered. That is, determine the minimum stock level, S_T, which satisfies

$$P_{max} \leq \sum_{k=0}^{S_T-1} \frac{e^{-\lambda_T}\lambda_T^k}{k!}$$

where

$$\lambda_T = \sum_{\text{aircraft}} \lambda_i \text{ (for each aircraft)}$$

and is the same as the total pipeline quantity defined earlier for complete pipeline coverage.

COMPARISON OF ALTERNATIVE SUPPLY POLICIES WITH THE AVCAL

Figure V-2 compares the optimized AVCAL with the current AVCAL[3] with respect to aircraft availability at day 90 in the steady-state wartime scenario. Note that the improvement is most significant in the availability prior to WRA cannibalization. This implies that proportionally less cannibalization is required under the optimized AVCAL. Figure V-3 shows the effect of increasing the overall spares coverage by covering all pipelines with an 85 percent fill rate criterion. This considerably improves the no-cannibalization availability measure and somewhat improves the full-cannibalization availability measures. For the S-3A a 33 percent increase in expenditure for spares causes about a 7 percent increase in full-cannibalization availability and a 60 percent increase in no-cannibalization availability. Note in comparing Figs. V-2 and V-3 that the optimization at AVCAL costs improves the no-cannibalization FMCA more than the increased expenditure for the F-14A.

An important finding in the examination of the extended pipeline coverage and the fill rate objective was that it was necessary to provide AVCAL additives as well as the extended pipeline coverage. The additives provide protection from stockout for those components with incorrectly predicted demands or repair times. That is, the fill rates used in computing stockage requirements might vary considerably from those projected with the actual removal, repair, and AWP rates. Without the additives the extended pipeline calculation and fill rate objective did worse in some cases than the current AVCAL with additives despite

[3] The current AVCAL is assumed to have the additives discussed earlier.

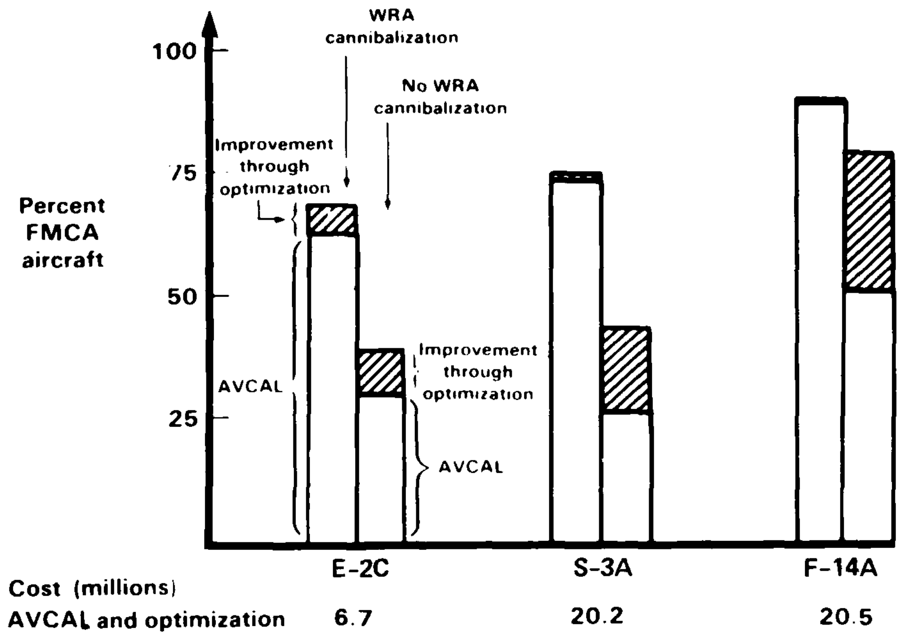


Fig. V-2—Comparison of the current AVCAL with optimization at the AVCAL cost — day 90 of scenario

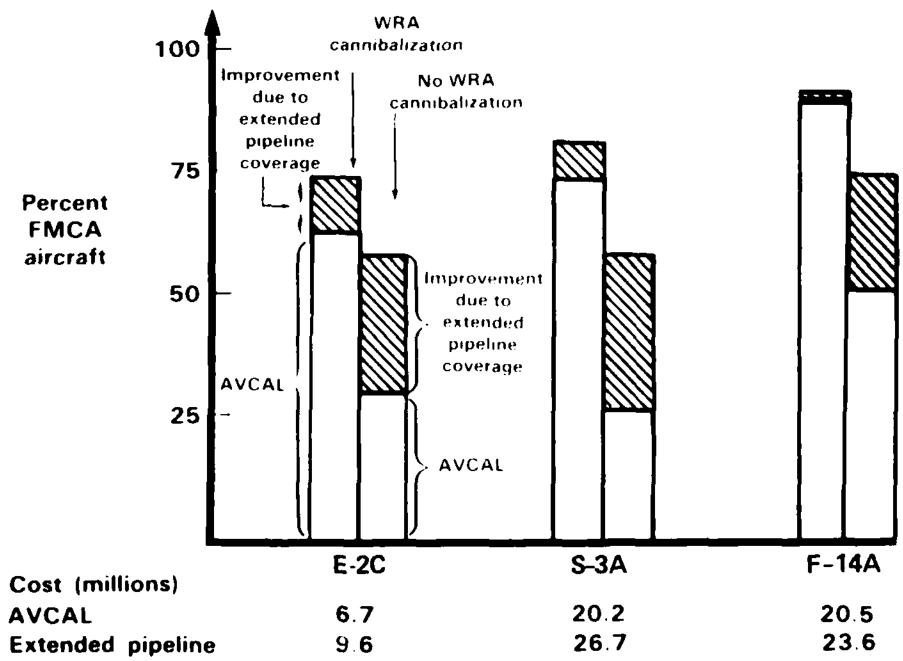
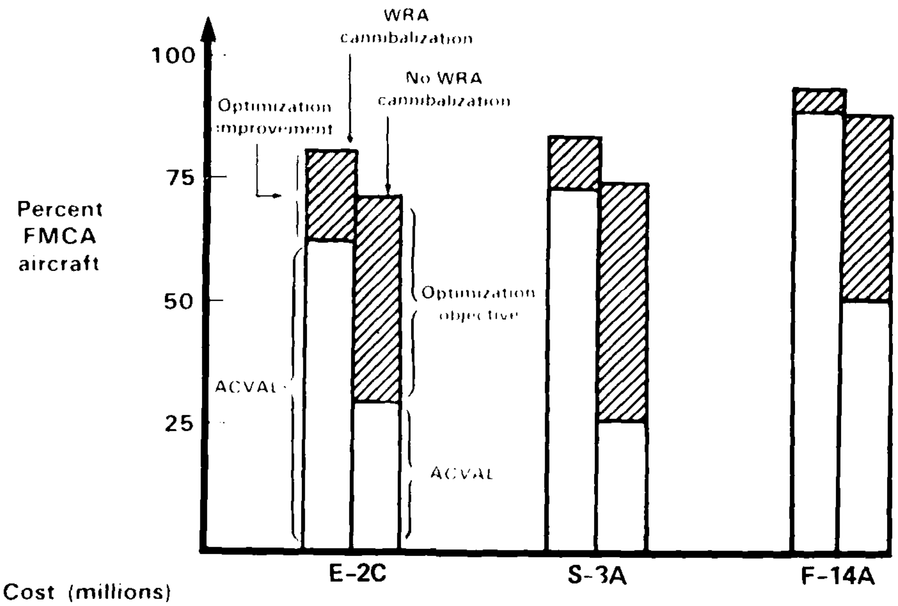


Fig. V-3—Comparison of the current AVCAL and increased pipeline coverage — day 90 of scenario

the higher expenditure. The additives also provide a low cost rule for increasing the range of low demand components stocked and reducing the probability of shortages and AWP for low cost, low demand components. Attempting to achieve the same range by adjusting the fill rate objective (to 95 percent, say) is much more expensive since high cost components must then also receive more stock. As can be seen in the results, the increased range of coverage for low demand, low cost items pays off in aircraft availability. The optimization technique did not include additives, but a fill rate criterion of 95 percent was used on consumable items to achieve essentially the same or better protection as the AVCAL for those components at low cost (compared with the rest of the AVCAL). The selection of the target NMCA rate for the optimization also affected the range of stock provided. Selection of a number higher than one would increase the depth of some components while reducing the range. The value of one was most successful in competing with the AVCAL and extended AVCAL.

Figure V-4 illustrates the improvement possible with an aircraft availability objective and the higher expenditure used for the extended AVCAL with fill rate objective. Note that the requirement for cannibalization is reduced to a point at which the performance without cannibalization is almost equivalent to the full cannibalization performance. Furthermore, under full cannibalization, aircraft availability for the avionics suite of components is up to 80 percent for each of the three aircraft types.



Cost (millions)	E-2C	S-3A	F-14A
AVCAL	6.7	20.2	20.5
Extended pipeline and optimization	9.6	26.7	23.6

Fig. V-4—Improvement possible with an aircraft availability objective and increased pipeline costs — day 90 of scenario

SUMMARY OF FINDINGS AND RECOMMENDATIONS: ALTERNATIVE SUPPLY POLICY

Current AVCAL range additives are important for providing stockage protection against demand estimation uncertainty. The study has shown that additives increase aircraft availability in the current AVCAL and are necessary even when the AVCAL is extended for more complete pipeline coverage. They were not necessary in the optimization technique investigated, but that technique was adjusted to obtain a range of stockage equivalent to that provided by the additives.

The extended AVCAL pipeline coverage improves aircraft availability and reduces cannibalization requirements. Additional expenditures for more complete coverage of transportation pipelines with stock safety levels pay off, particularly in the reduction of WRA cannibalization requirements.

A simple optimization method with an aircraft availability objective improves performance and reduces cannibalization requirements compared with either the AVCAL or extended pipeline coverage. For the same dollar expenditure, an optimization technique, requiring only slightly more information than the current AVCAL process, and which uses an aircraft availability objective, improves performance above that obtained with the fill rate supply objective. With this technique aircraft availability based on avionics components can reach reasonable levels (when retail and wholesale supply requirements are fully satisfied).

Based on these findings the following are recommended.

1. Range additives or other methods of providing extended range of stockage protection should be included in future spares requirements methods.
2. The aircraft availability objective and simplified optimization technique should be considered for use in future modifications of the AVCAL process and also for initial outfitting (initial spares procurement for new aircraft).
3. Investigate improved methods for collection and use of data for supply requirements computation. Since range additives are necessary to overcome forecasting errors in demand and repair estimation and only simple optimization techniques can be proposed because of inaccuracies in configuration data, improving the data collection system should pay off handsomely in improved ability to project spares requirements. Furthermore, since many of the components show very low demands

and hence large uncertainty regarding forecasts, statistical techniques (Bayesion techniques, for example) may improve prediction of needs during a deployment.

VI. TRANSPORTATION ANALYSIS

REVIEW OF THE ROLE OF TRANSPORTATION IN THE CURRENT STRUCTURE

Figure VI-1 illustrates the current dependency on transportation of a deployed carrier's aircraft component repair. Components which are not carrier reparable (BCM) must be shipped back to CONUS via retrograde transportation and orders for replacement components must be shipped via outbound (order and ship) transportation. When these transportation links are broken, the carrier air wing must operate out of its AVCAL spares which, as was shown in the previous chapter, do not provide adequate protection for these pipelines. This chapter will further illustrate the dependency of carrier aircraft availability on transportation.

The typical method of transport of small components to a deployed carrier is air parcel post to the operating theater and by carrier on board delivery (COD) aircraft to the ship within the theater. Larger components are typically moved to the theater by the Military Airlift Command (MAC) and then delivered by COD. The alternatives to these modes include other forms of mail and surface ship or helicopter delivery within the theater.

Outbound transportation time is measured from the time a part is ready for shipment at the issuing stock point until it is recorded as received aboard the deployed carrier. Order and shipping time (O&ST) includes order, order processing, and transportation time. Retrograde transportation time is measured from the time a component is declared BCM until it is received at a Naval Air Rework Facility (NARF).

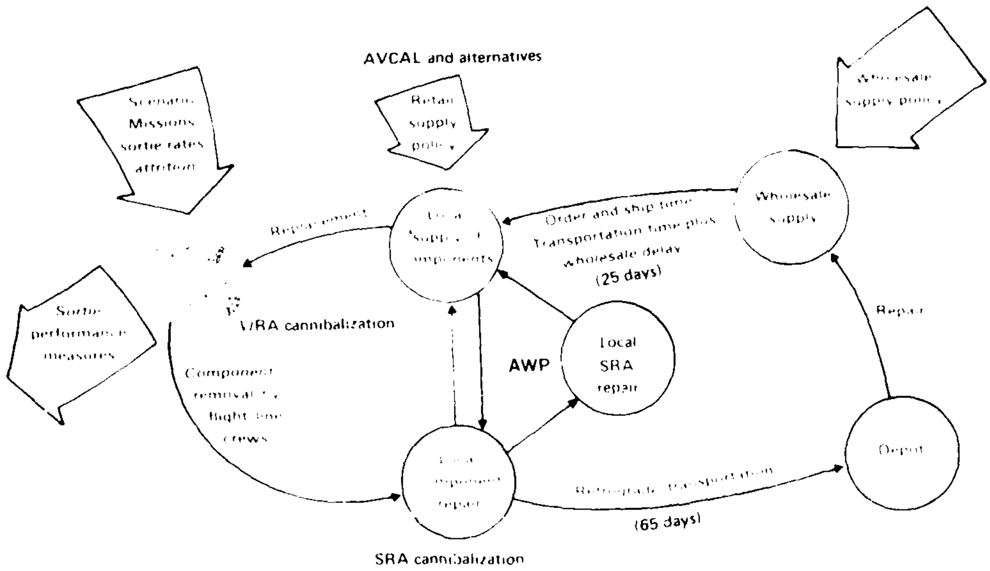


Fig. VI-1—Current average transportation times and the pipelines they affect

Transportation priorities depend on the type of cargo, the priority of the requisitioner, and the urgency of need. The priority of retrograde cargo is generally determined by the type of materiel to be shipped and the priority of O&ST cargo is determined by the urgency of the requester. In general, outbound components causing holes in aircraft are shipped via the highest priority, and components ordered to fill shelf stock and most retrograde shipments are given lower priorities. CLAMP items, which are specially managed components, are also shipped with a high priority. The high priority items are usually sent by air to the deployed carrier, whereas the lower priority items are shipped by surface transportation and low priority air transport. For a more complete description of priorities and modes of transport, see Ref. 6.

TRANSPORTATION PERFORMANCE OF THE CURRENT STRUCTURE

For the CABAL study, the determination of transportation times in peacetime and wartime has been a CNA responsibility. Reference 6 describes the CNA analysis of transportation time in peacetime. Table VI-1 shows the range of times for O&ST and retrograde shipment based on the CNA study. These times depend on the type of item, mode of transportation, priority, and theater. Generally, shipments to the Western Pacific and Indian Ocean theaters take longer than shipments to the Mediterranean theater. For study purposes we used an average outbound time of 25 days and average retrograde time of 65 days.

The long times for retrograde shipments (which cover the same distance as outbound shipments) are apparently the result of low priority combined with long holding times (an average of seven days on carriers) before shipment. The long retrograde times affect the operating forces by tying up the AVCAL stocks in transportation pipelines (recall from the supply discussion that no wholesale stocks are provided for the retrograde pipeline). For the set of components considered in this study, about $12 million worth of components per carrier is used to cover the additional 40 days of retrograde

Table VI-1

RANGE OF OUTBOUND AND RETROGRADE SHIPPING TIMES
(Days)

Operating Area	Outbound	Retrograde
Western Pacific	15-35	4[illegible]-61
Mediterranean	14-29	40-60
Indian Ocean	23-39	50-65

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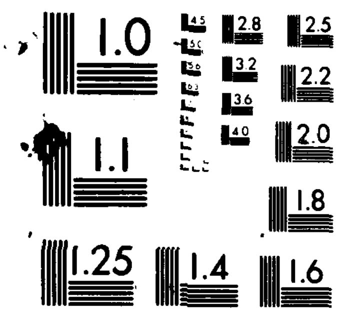

MICROCOPY RESOLUTION TEST CHART
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transportation. That is, if retrograde and O&ST times were the same, at least \$12 million less in aircraft components would be tied up in transportation. Associated with each deployed carrier is \$290,000 worth of components for each day of retrograde shipment in wartime and about half that in peacetime.

The CABAL study projected the effect of these transportation times on component shortages and aircraft availability in wartime. We assumed that the times would remain the same in wartime although the effect of transportation interruption (such as might occur as higher priority combat supplies are shipped) was also considered. The previous chapter showed the performance of the current structure under the current O&ST and retrograde transportation times. An interesting (and perhaps obvious) finding of our study of performance showed that reduction of the retrograde time would have little effect on performance during wartime scenarios less than about 100 days long because the round-trip time of a component would be that long even under the optimistic assumption that retrograde times could be reduced to outbound times. The primary effect of the longer transportation times is to absorb components, leaving later deployed carriers deficient in AVCAL stocks and ultimately affecting the ability to maintain a sustained level of effort beyond 100 days.

The long transportation times have important implications for the DRMS alternative of shore repair. The stockage cost to fill 90 days of round-trip transportation is so large that it consumes most of the potential economies of scale of a larger shore-based facility. Furthermore, the ability to establish repair priorities at the shore

facility would be seriously affected by the remoteness of repair in time from the carrier. Again, had there been other savings by shore repair, the transportation time might have been reduced by expending some of the savings on management and airlift.

The analysis of VAST [Ref. 9] showed that it was likely to be overloaded in a wartime flying program and suggested that one important option was to work off the potentially large backlogs of VAST repair by using spare VAST capacity ashore. In this case also, the long retrograde times inhibit the ability to effectively employ these options.

EFFECT OF TRANSPORTATION DISRUPTION IN WARTIME

More immediate effects on aircraft availability occur when outbound transportation is disrupted. Figures VI-2 and VI-3 show the effect of a 30-day cutoff of outbound shipments from day 0 of the steady flying program scenario for two aircraft types. This type and period of cutoff are deemed likely in the event of an intense conflict as higher priority combat material is moved with available airlift. Note that even when full WRA cannibalization moderates the effects of the cutoff, the effect on aircraft availability is significant, considering that 90 days of "self-sufficiency" spares are provided in the current AVCAL. The lack of explicit coverage of O&ST and retrograde pipelines means that much of this self-sufficiency stock is used up during peacetime flying so that cutoff from resupply seriously affects performance.

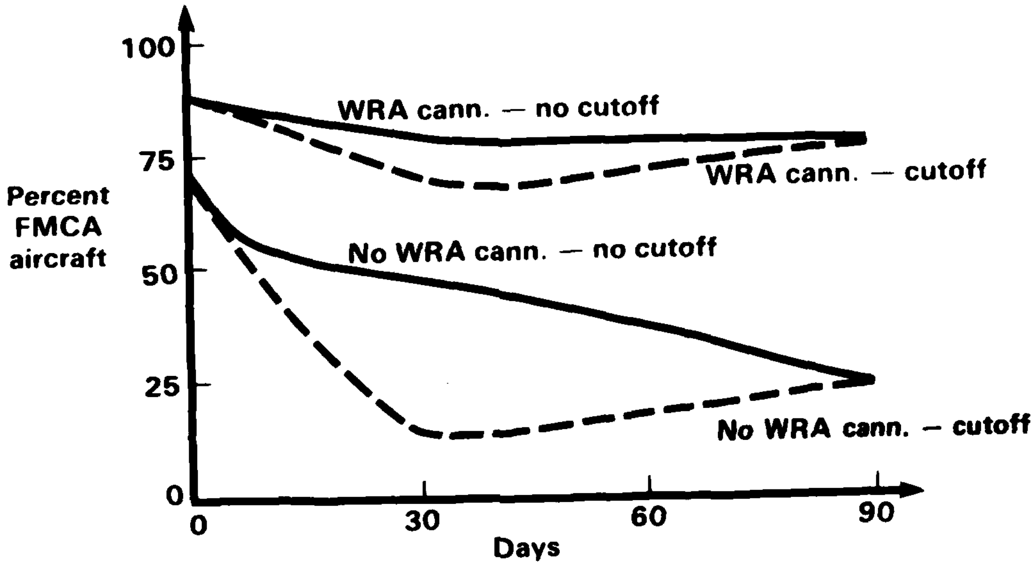

Fig. VI-2—Effect of transportation cutoff for day 0 to 30 on the S-3A avionics availability

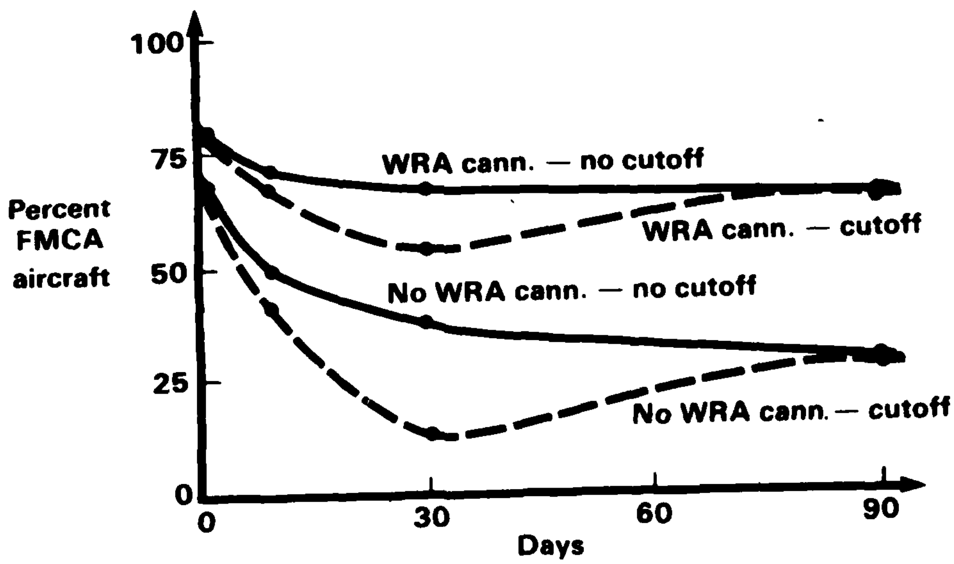

Fig. VI-3—Effect of transportation cutoff for day 0 to 30 on the E-2C avionics availability

SUMMARY OF FINDINGS AND RECOMMENDATIONS: TRANSPORTATION

The CNA study indicated that retrograde transportation times are currently very long compared with outbound times, and cited a combination of administrative processing delays and a shortage of COD airlift capacity as the reason for long retrograde times. Retrograde delays increase stockage costs, cause a draw-down of system assets to support carrier-based aircraft, and limit the Navy's flexibility to employ shore-based logistics capabilities in support of carriers. These delays also imply that the DRMS shore repair alternative would incur a significant cost penalty to fill the long pipelines.

Transportation cutoff, even in the early stages of a conflict, has a serious impact on aircraft availability and indicates that carrier air self-sufficiency is not as great as might be implied by "self-sufficiency" spares. Part of the problem is the fact that outbound and retrograde transportation times are not explicitly considered in the current stockage policy so that even peacetime flying rates draw down the carrier AVCAL supplies.

The following recommendations are based on this study of transportation effects:

1. Examine the potential to reduce retrograde times. It appears that large portions of these times are due to management and priority problems rather than to insufficient capacity.
2. Increase stockage protection against transportation cutoff. This can be done by some of the AVCAL extensions currently

under review, including explicit consideration of transportation pipelines and prepositioning of that stock aboard the ship. Establishing safety levels for BCM pipelines and adding additional endurance period spares also increase this protection.

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